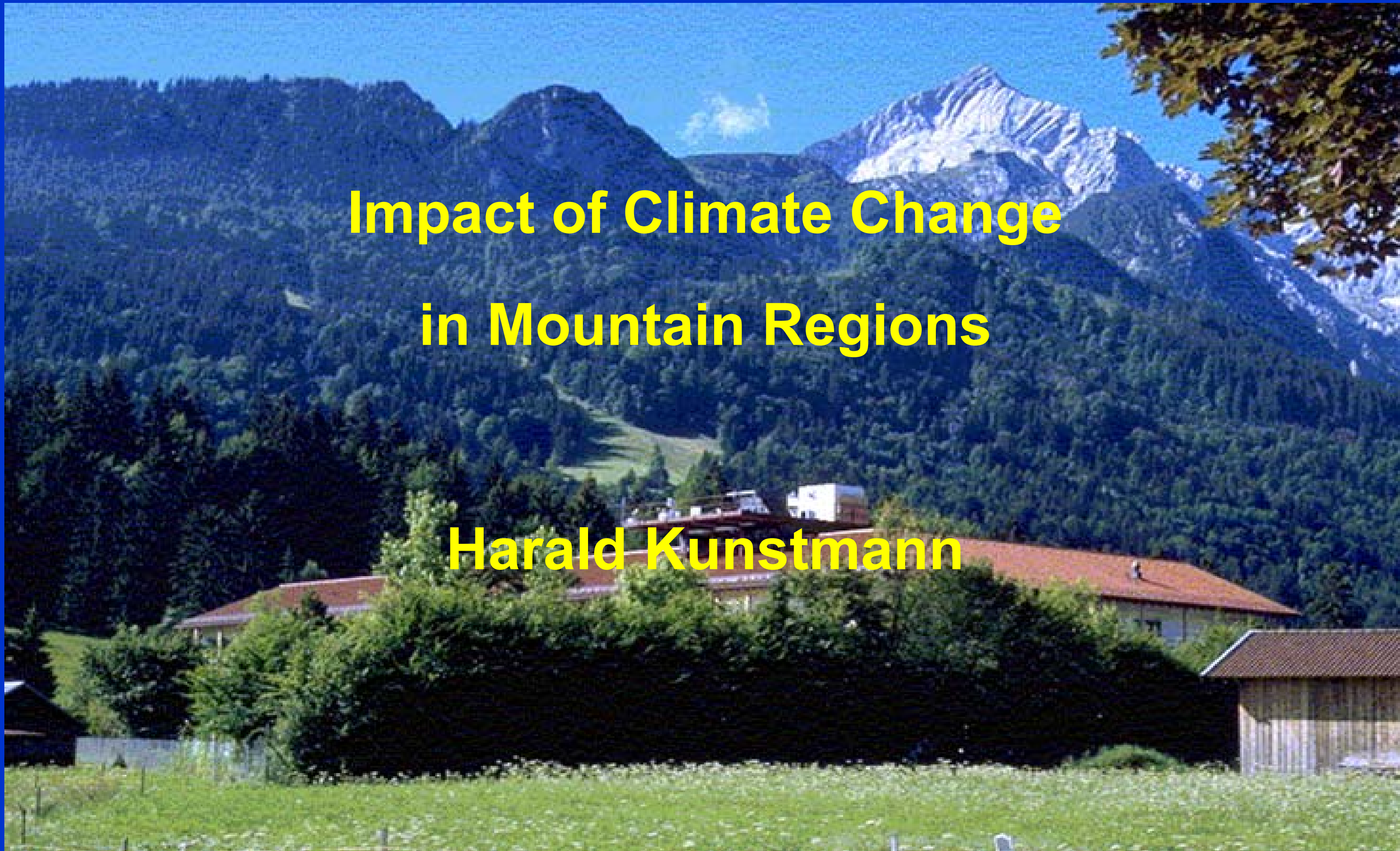
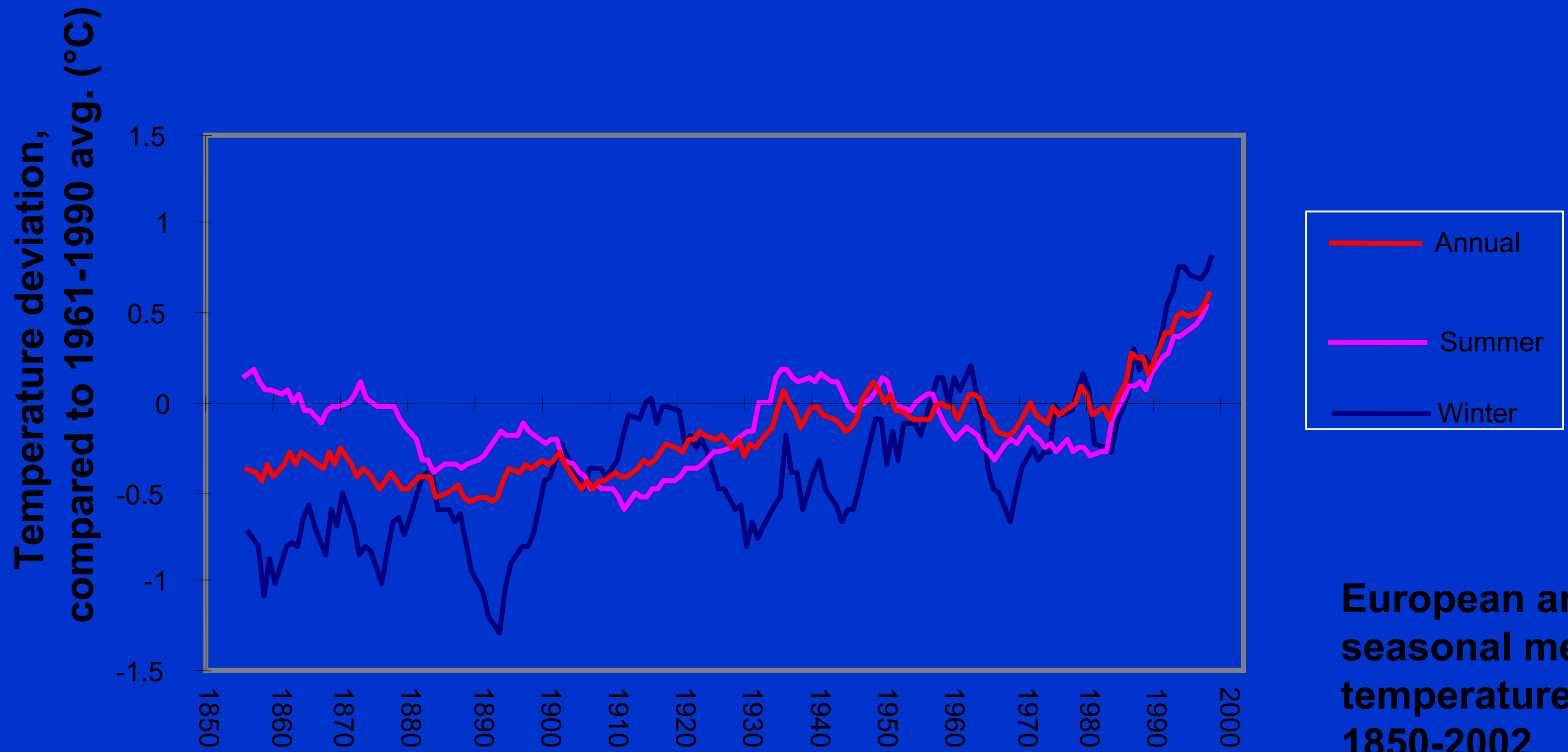


Impact of Climate Change in Mountain Regions

Harald Kunstmann

Motivation: Globaler Change – Global Warming



European annual and seasonal mean temperature deviations, 1850-2002

- Global Temperature: + 0.7 ±0.2 °C in past 100 years
- Europe: +0.95 °C; Alps +1.6°C
- Summer +0.7°C ; Winter +1.1°C

Climate Change Past 120 years

Global Scale:

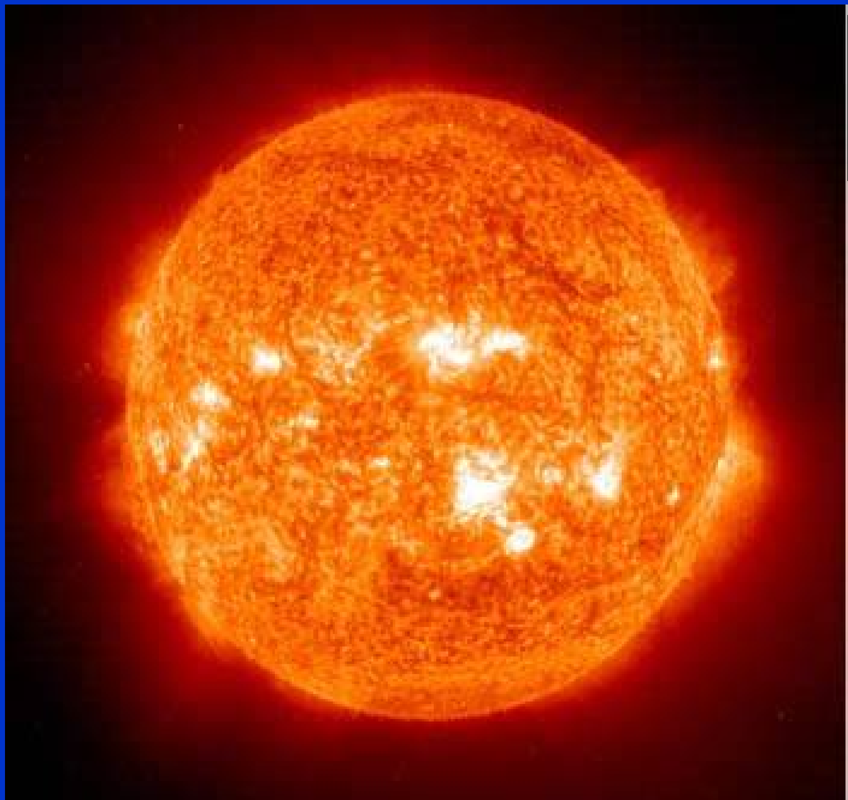
- ≈ 0.9 °C since start of temperature measurements in 1860;

  ≈ 0.6 °C past 30 years with maximum in 2005; largest increases in continental northern hemisphere (30°- 90° N)
- Increasing mean annual precipitation, however large regional differences; increasing number and intensities of meteorological extreme events

Alps (with regional differences):

- Increase of mean annual temperature up to 2.0°C
- Seasonal redistribution of precipitation: increase in late winter & spring (up to 20 - 30%) and decrease in summer (> 20%)
- Increasing number and intensities of meteorological extreme events (heavy precipitation, heat waves, storms)

Reasons for Climate Change

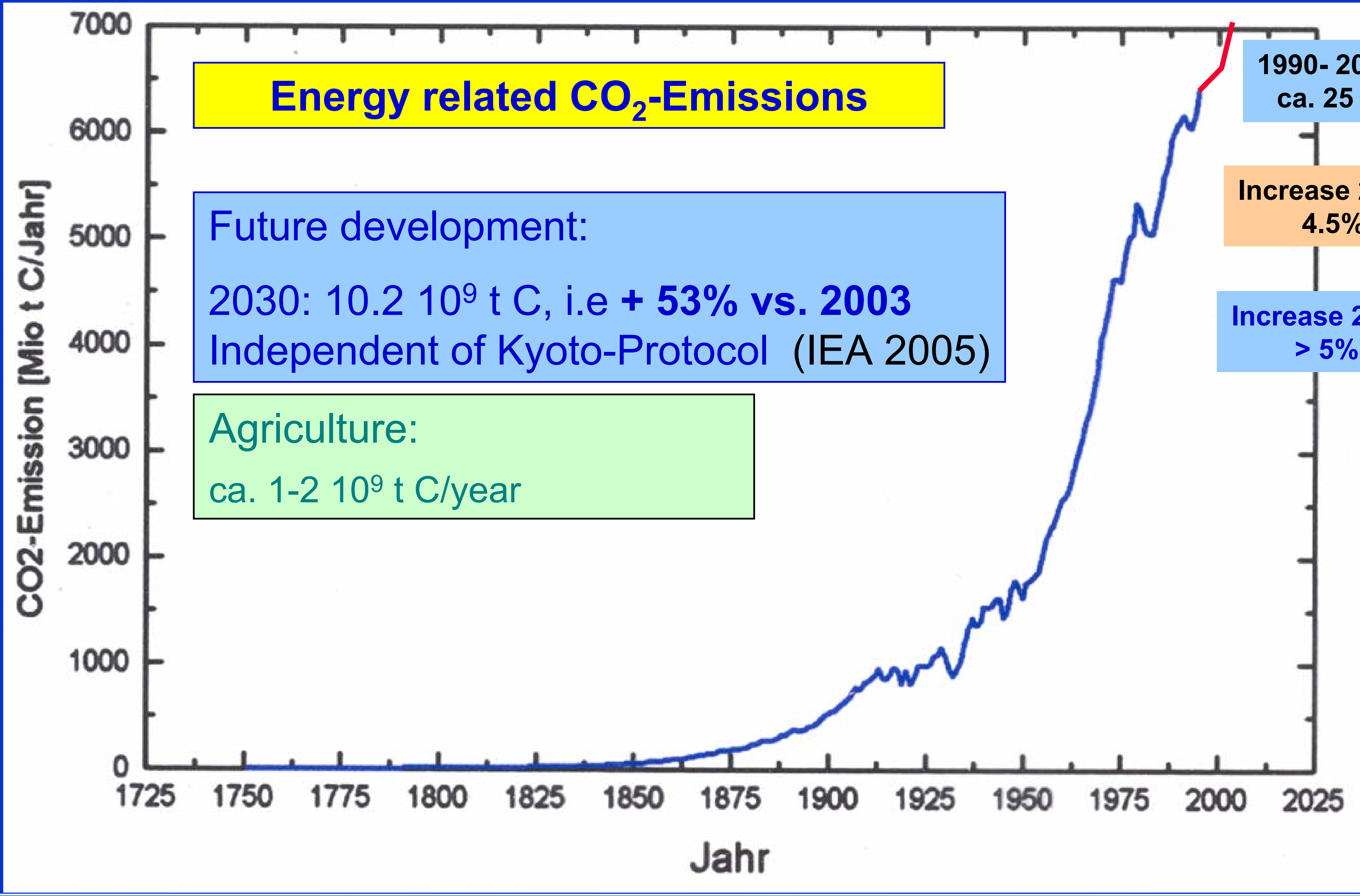


Solar radiation change: ca. 30%

Anthropogenic activities: ca. 70%

Greenhouse gases (CO_2, CH_4, N_2O, O_3, FCKW)
-18°C → +16°C

Energy related CO_2-Emissions



Future development:

2030: 10.2 10^9 t C, i.e **+ 53% vs. 2003**
Independent of Kyoto-Protocol (IEA 2005)

Agriculture:

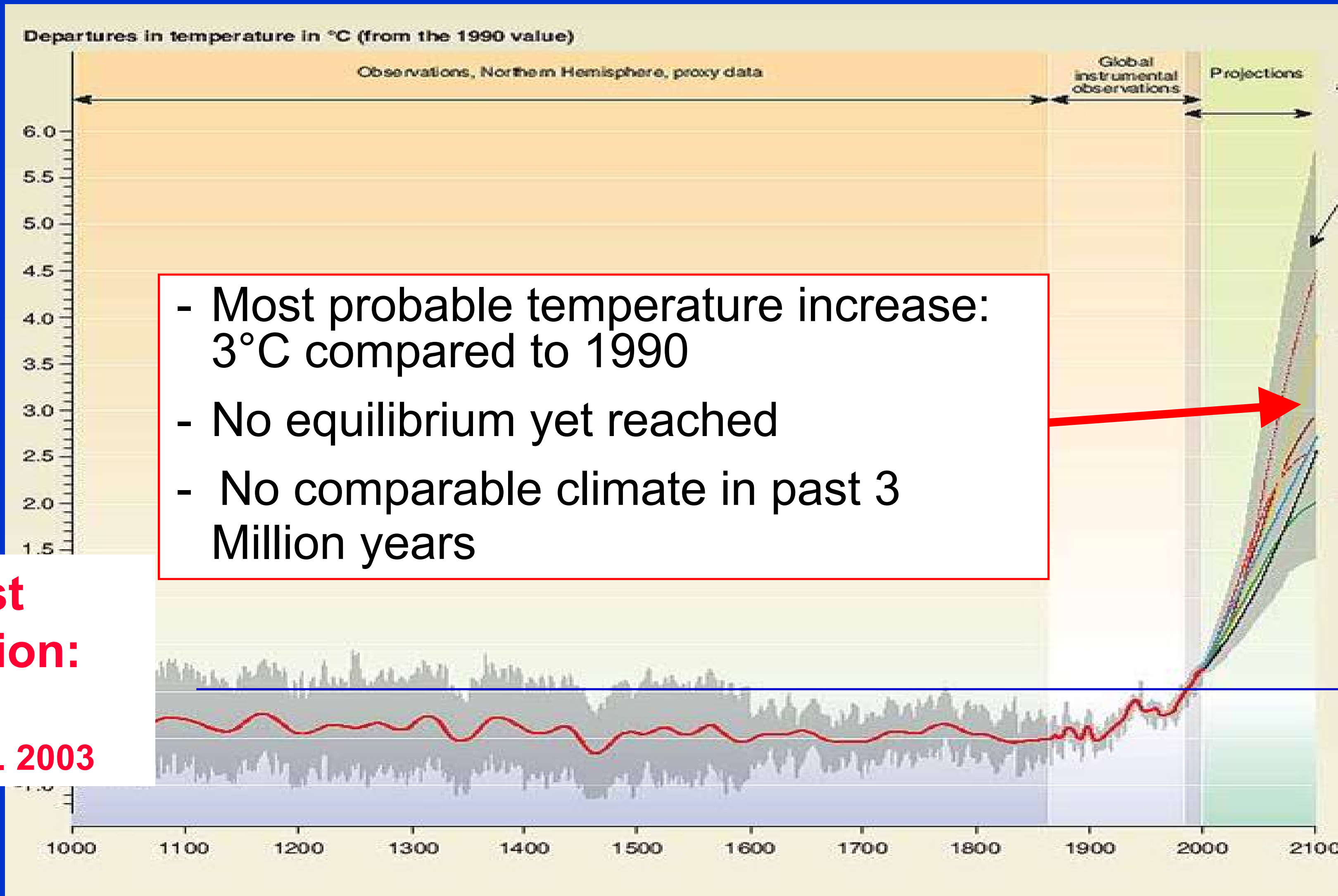
ca. 1-2 10^9 t C/year

1990- 2004:
ca. 25 %

Increase 2004:
4.5%

Increase 2005:
> 5%

Temperature Development: Past and Future



- Most probable temperature increase: 3°C compared to 1990
- No equilibrium yet reached
- No comparable climate in past 3 Million years

Range 1.4- 5.8°C

Latest estimation: 4°C
Jones et al. 2003

General Problems Accompanying Global Warming

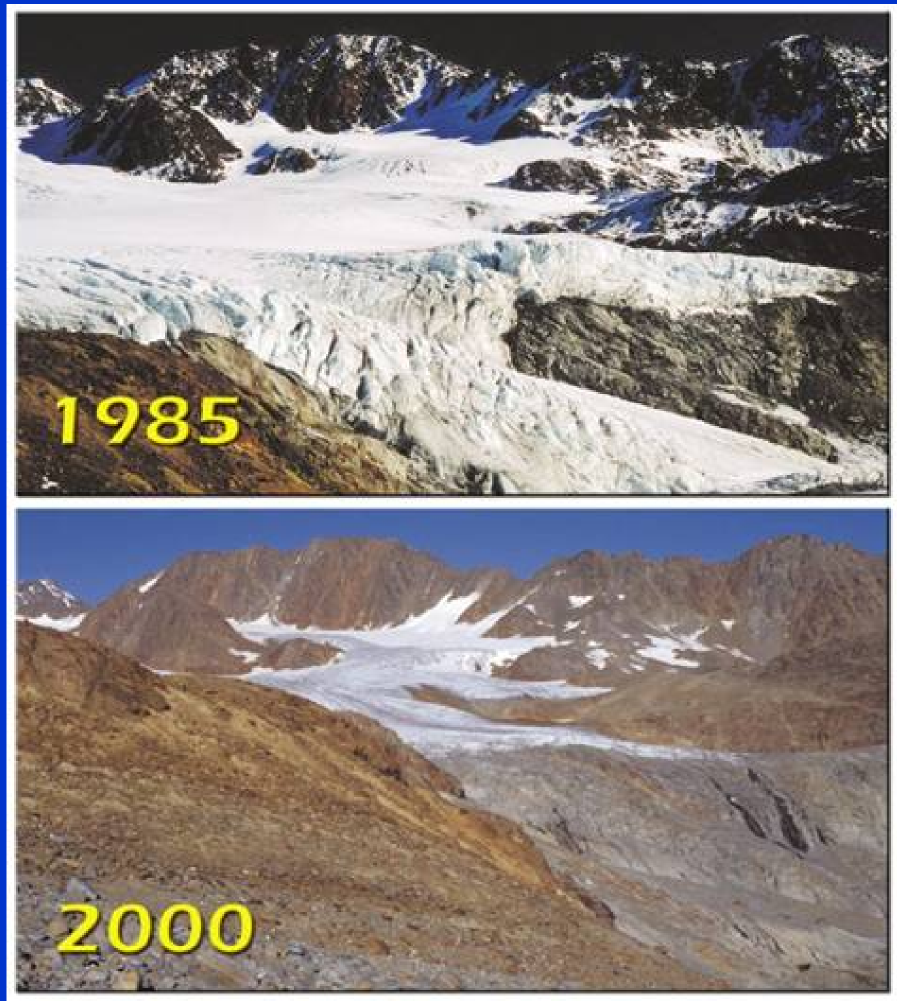
- Sea level rise : 30-50 cm
- Change in atmospheric circulation, shift of vegetation zones (150 km per °C)
- Intensification of the water cycle
- Positive feedbacks, e.g.: 1) Water vapor
  2) Defrosting of permafrost soils & microbial activity (CO_2, CH_4)
- Regional trends can differ tremendously from global trends

Specific Hydrological Problems in Mountain Regions

- Extremely fast precipitation-runoff response times
- Extremely short warning times
- Already small “additional” precipitation amounts can lead to extreme runoff events
- Precipitation intensities are expected to increase under climate change
- Due to orography: small atmospheric circulation changes can induce large regional/local hydrometeorological changes

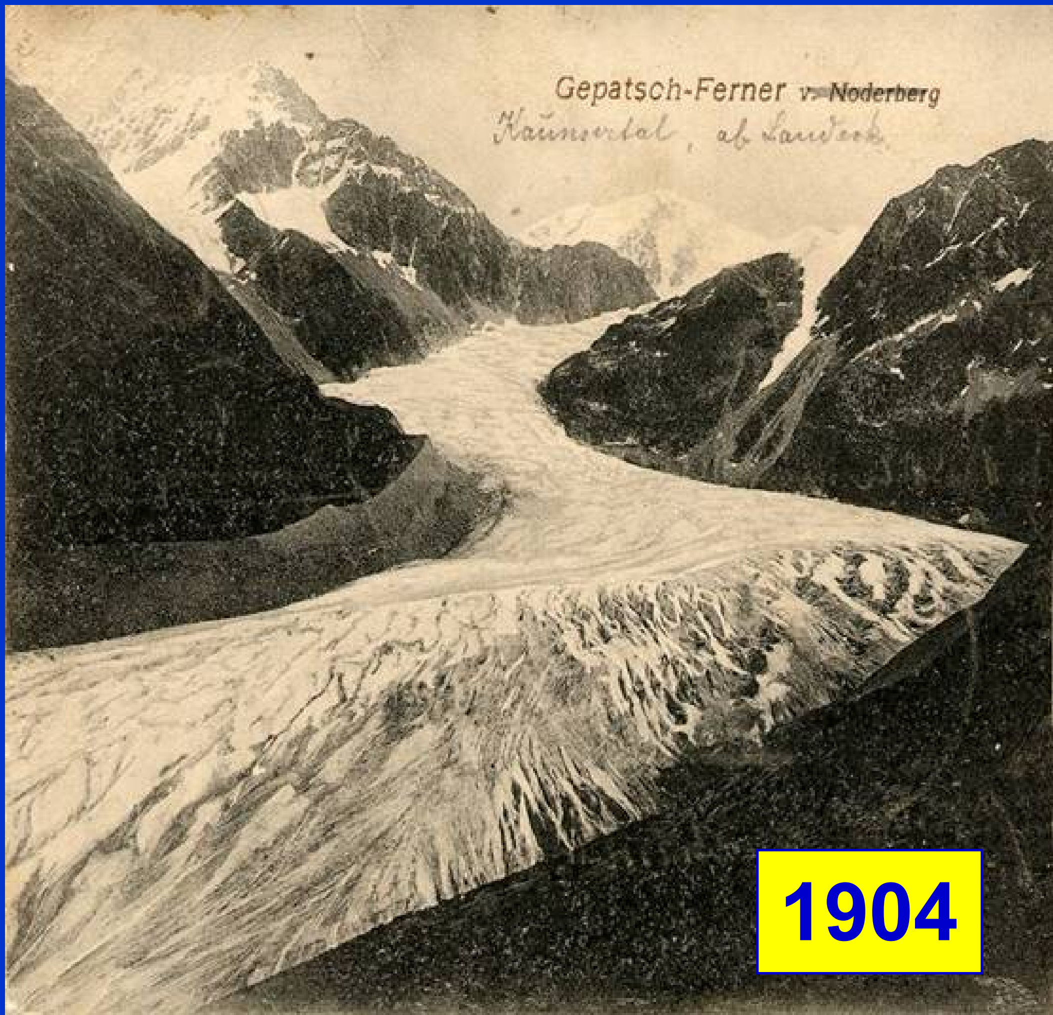
Silent Footprints of Climate Change: Glaciers

- 50% Mass loss 1850-1980 in Alps
- 20-30 % 1980–2000
- 10% Sommer 2003



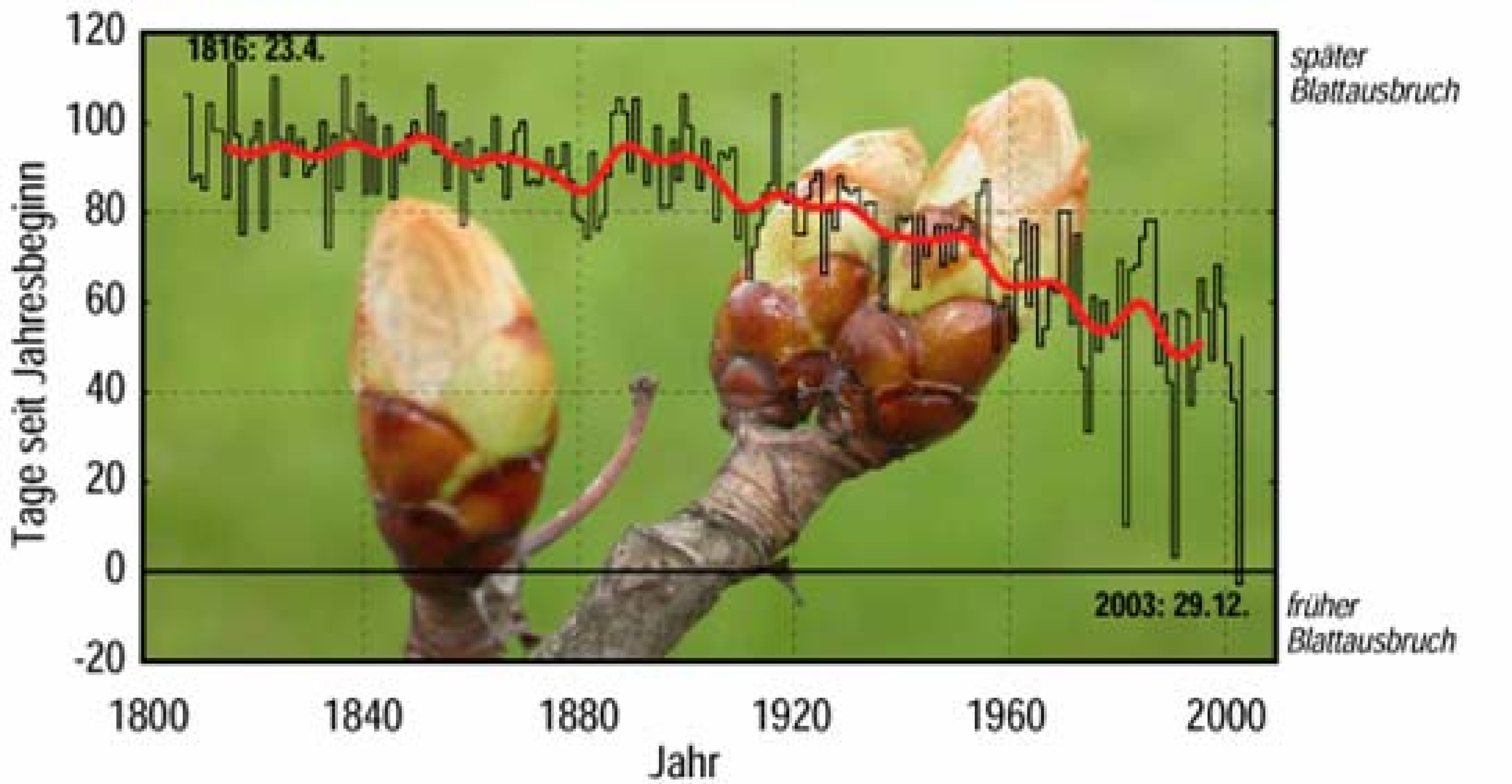
Vernagtferner

Gepatsch-Ferner Glacier, Kaunertal (Tirol)



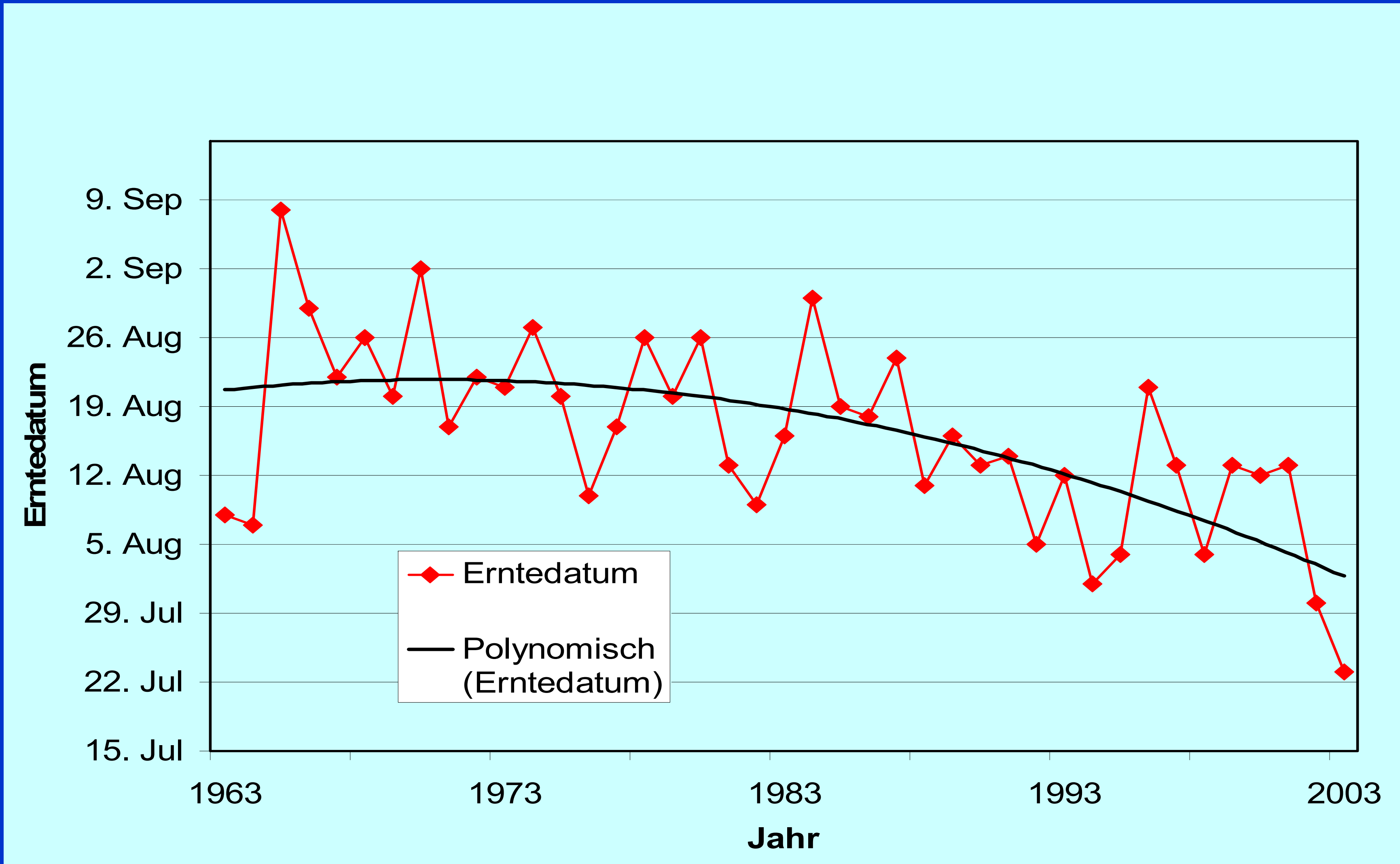
Source: Gesellschaft für ökologische Forschung, München

Silent Footprints of Climate Change: Vegetation

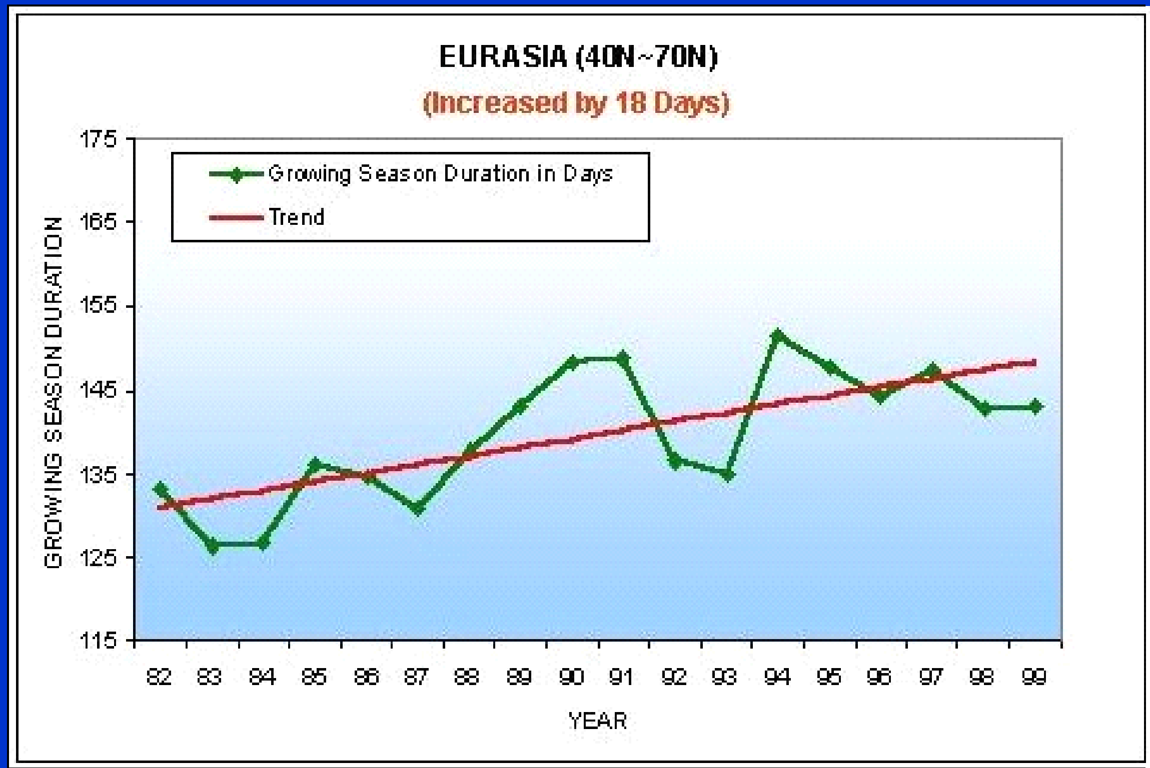


Onset of leaf shoot, Rosskastanie – Geneve 1808-2004

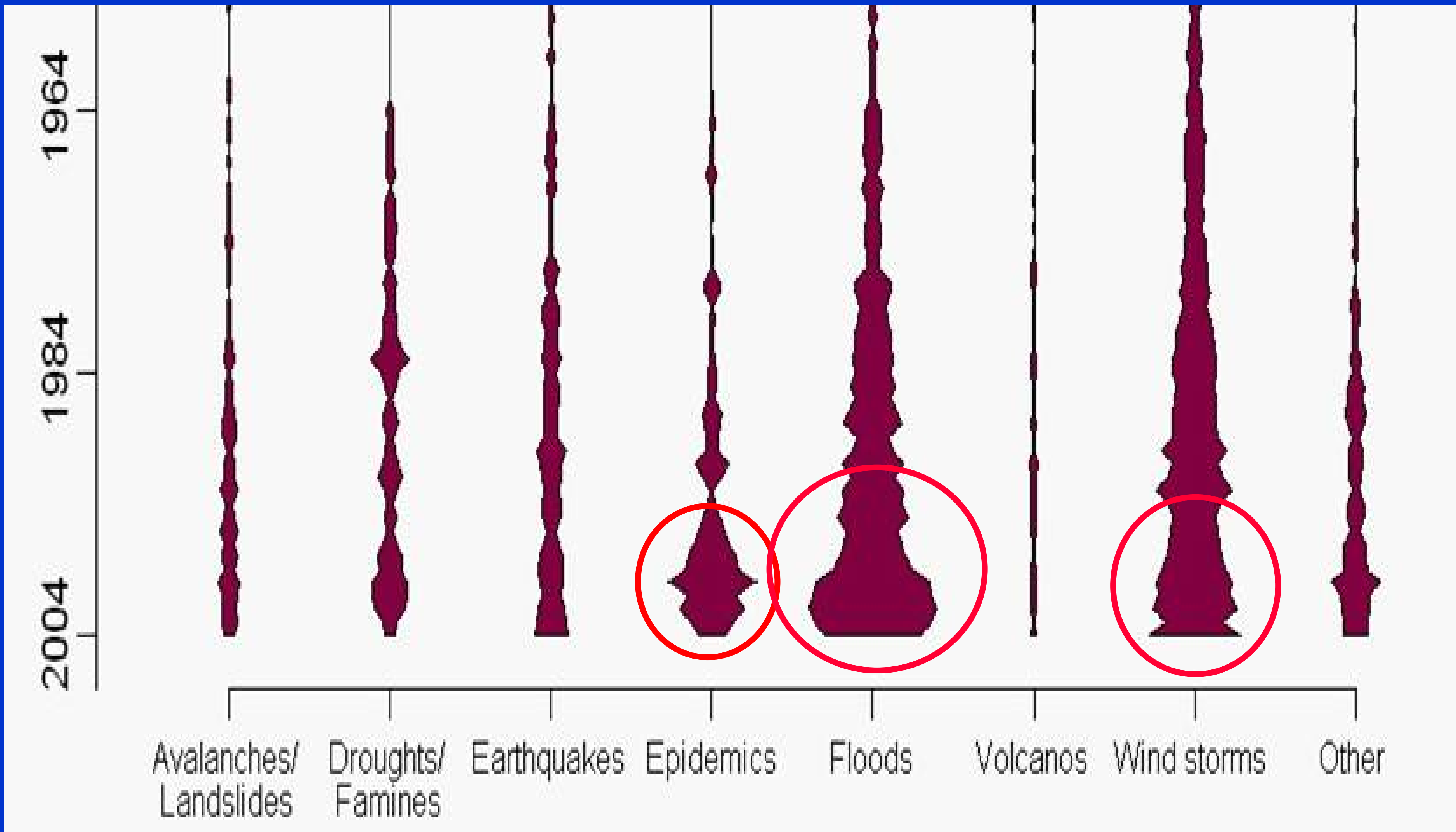
Harvest Date Winterwheat in Lower Bavaria



Change of Vegetation Period 1982 - 1999



Non-silent footprints: Temporal development of natural hazards



Looking into the Future: Climate Scenarios

Population Growth   Economic Development
Technological Progress

↓

Emission Scenarios
Greenhouse Gas Concentrations

↓

Global Climate Models

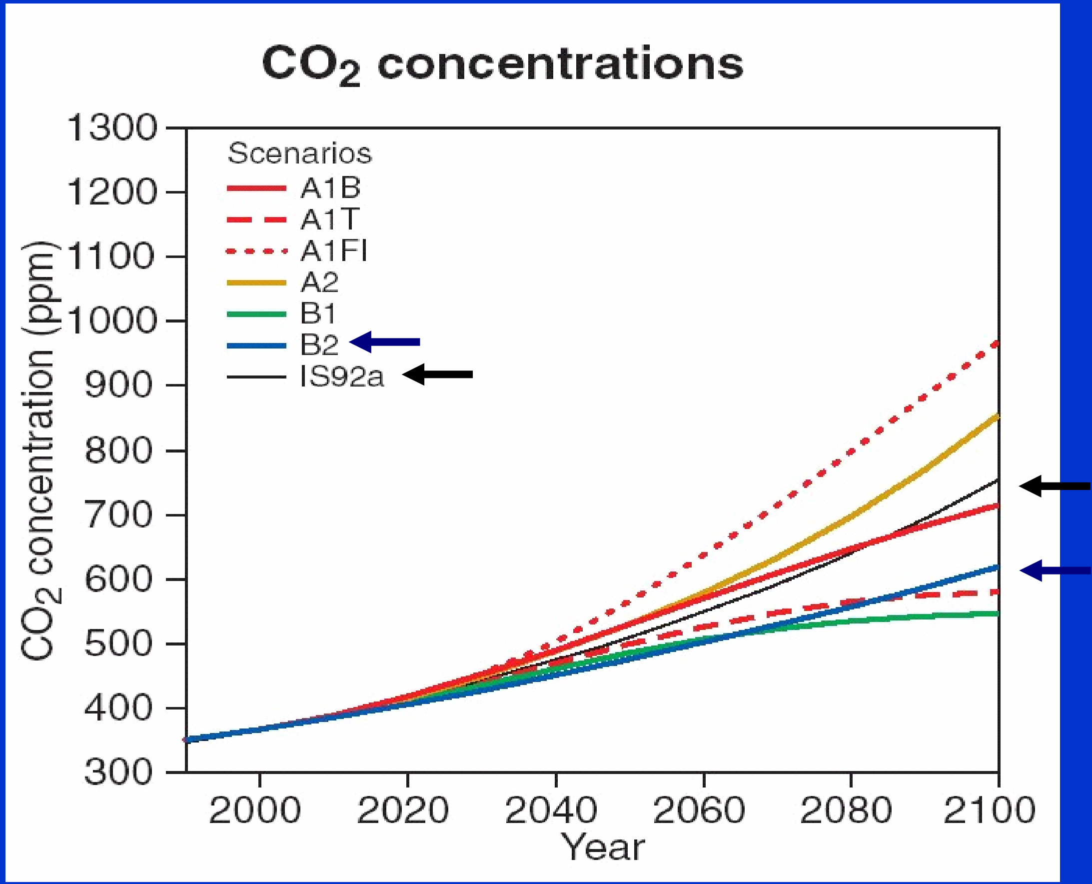
↓

Global Climate Scenarios

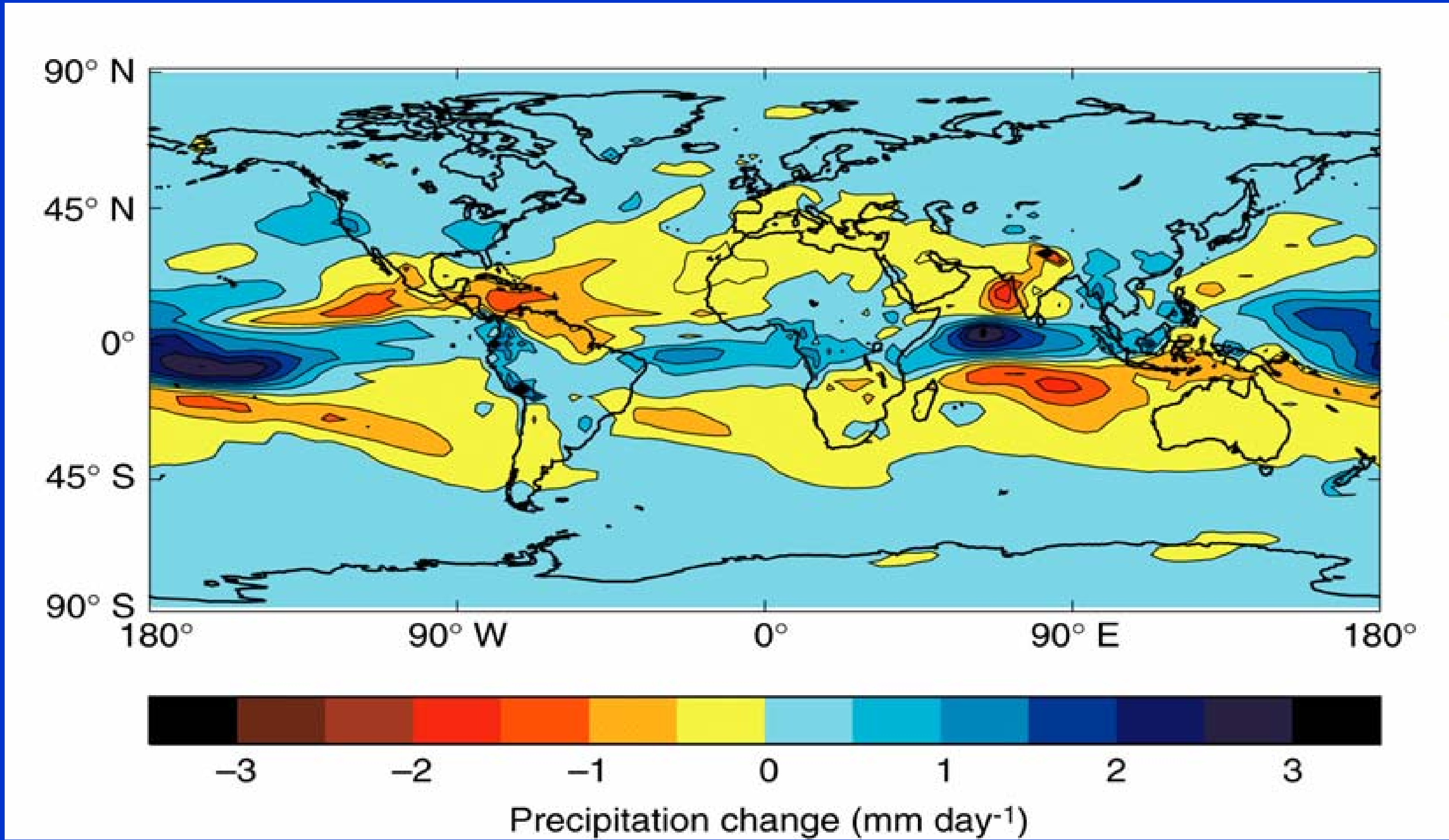
Looking into the Future: Climate Scenarios

- Our studies:
  scenario B2
  (“local solutions”)
  scenario IS92a
  (“business as usual”)

- Focus on time slices
  B2: 1960-1989 & 2070-2099
  IS92a: 1991-2000 & 2030-2039



Global Climate Scenarios: Projected Changes in Annual Precipitation for the 2050s



Hadley Centre for Climate Prediction and Research

⇒ Resolution too coarse for regional impact analysis !

Population Growth Economic Development
Technological Progress

↓

Emission Scenarios
Greenhouse Gas Concentrations

↓

Global Climate Models

↓

Global Climate Scenarios

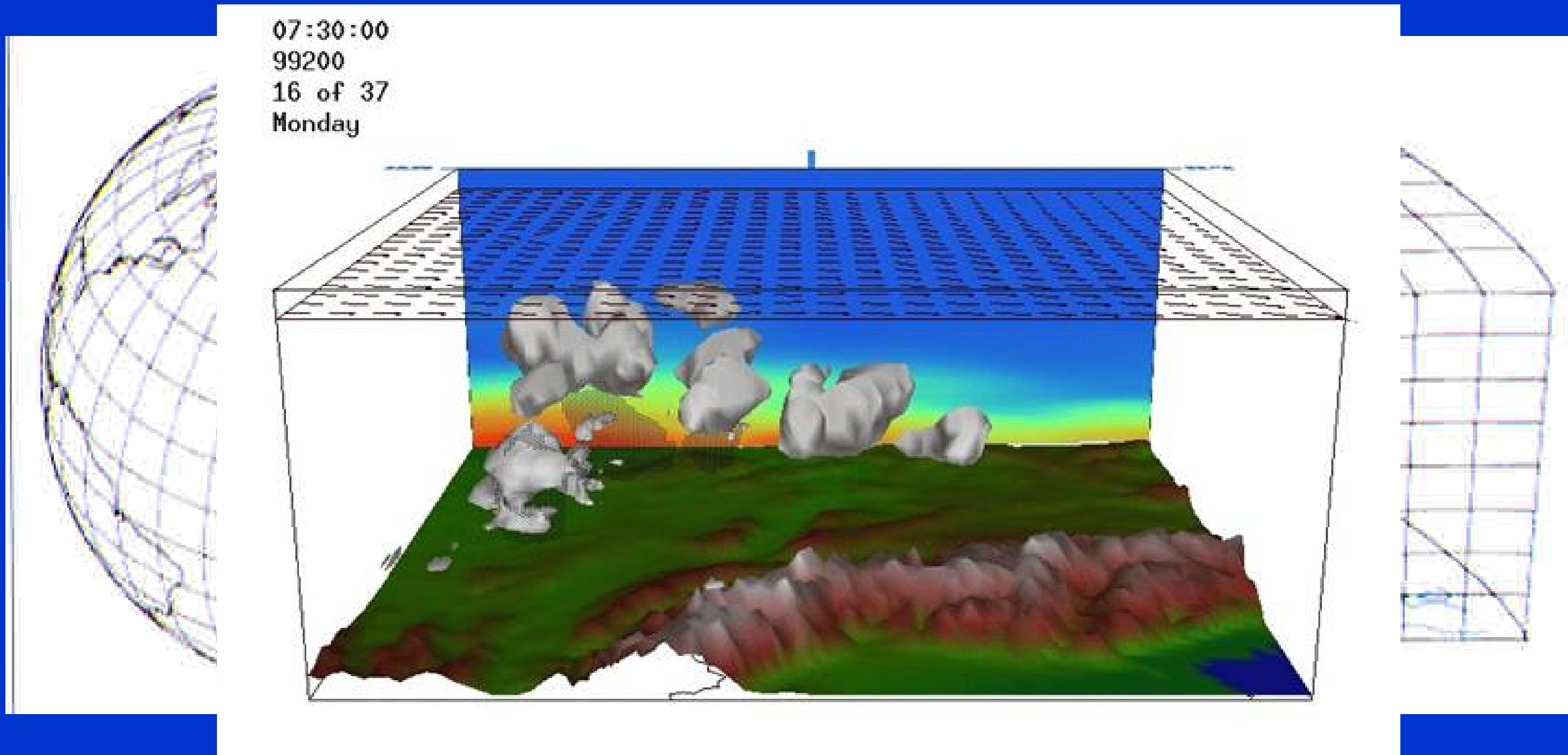
↓

Downscaling Methods

↓

Regional Climate Scenarios

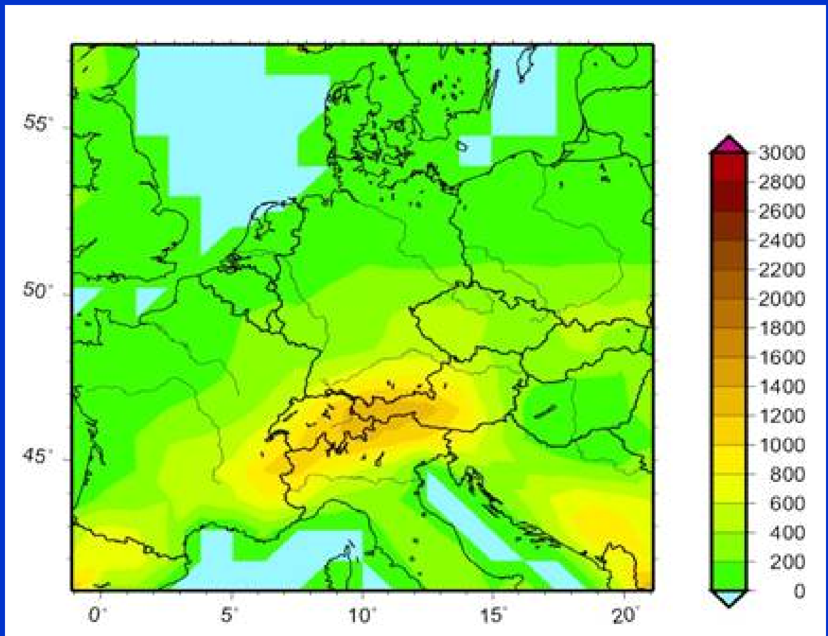
Looking into the Future: Regional Climate Modeling



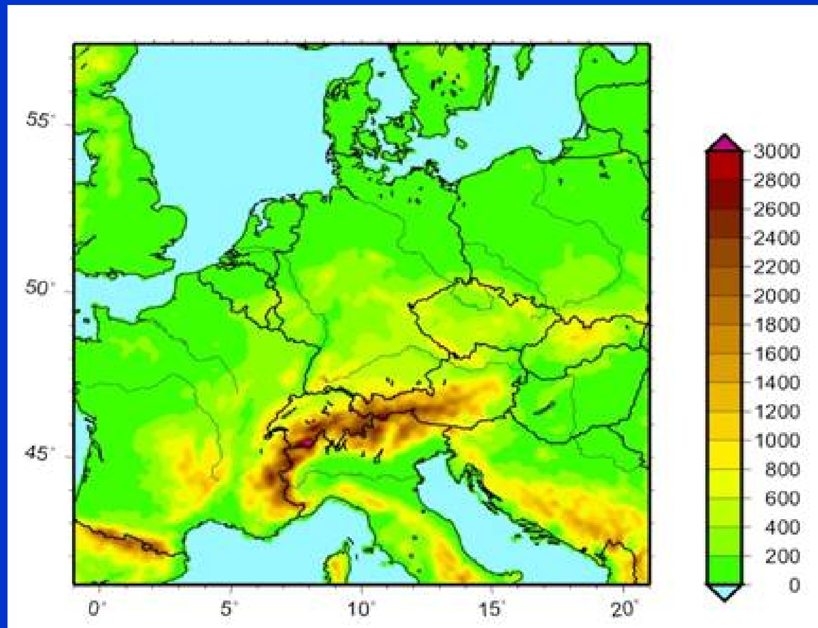
Explicit dynamical downscaling:
Numerical simulation of atmospheric processes
by finite difference schemes solving atmospheric PDEs

Looking into the Future: Regional Climate Modeling

Orography with different resolutions



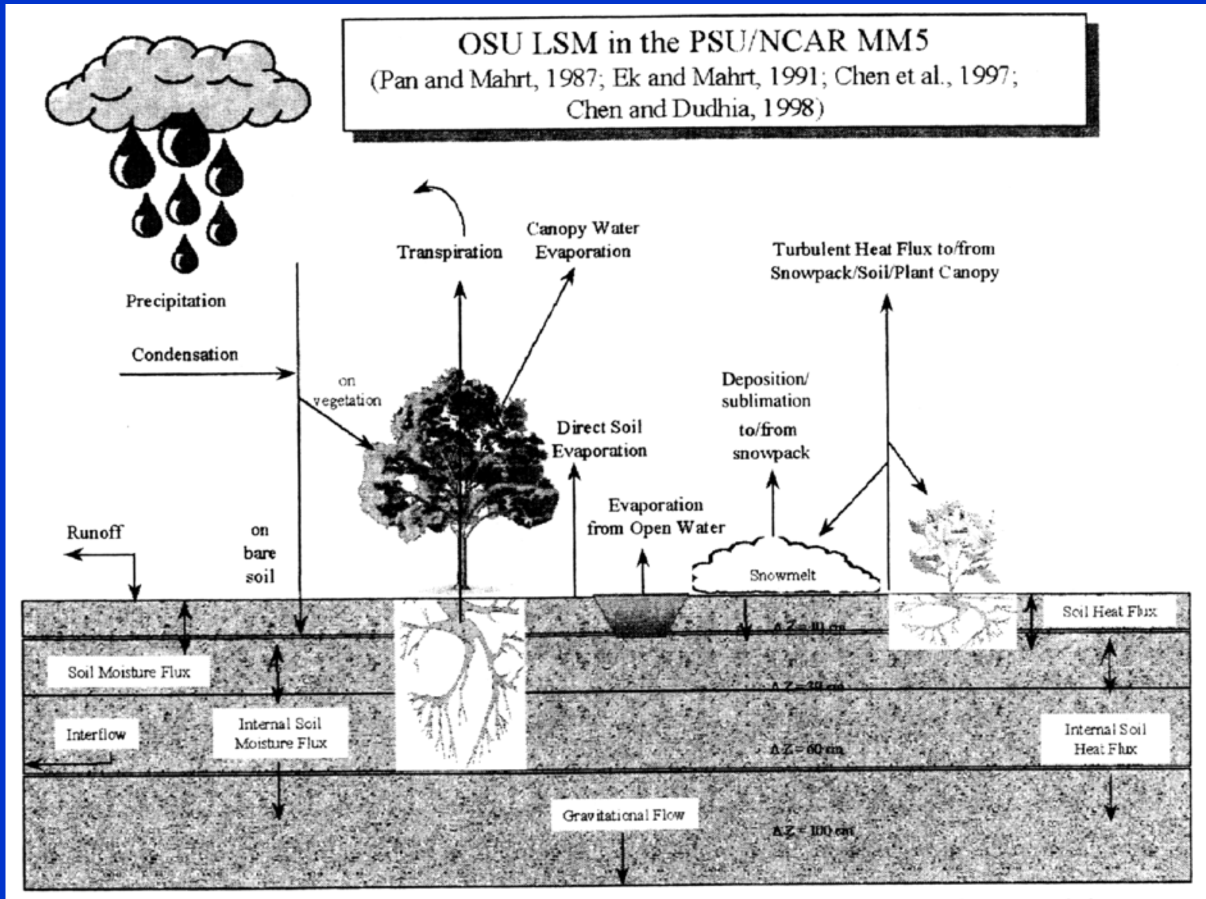
Δ = 100 km



Δ = 10 km

Looking into the Future: Regional Climate Modeling

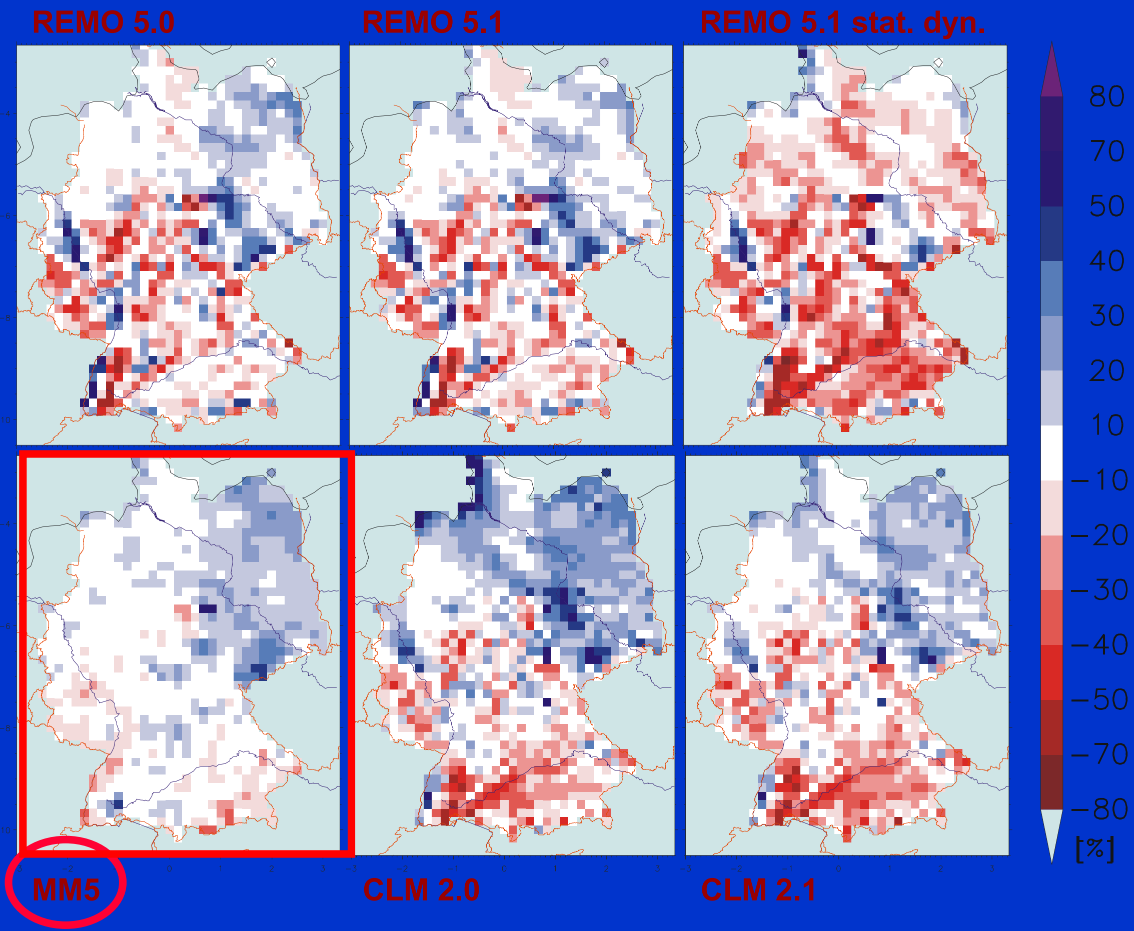
Lower boundary for atmospheric model: SVAT-model



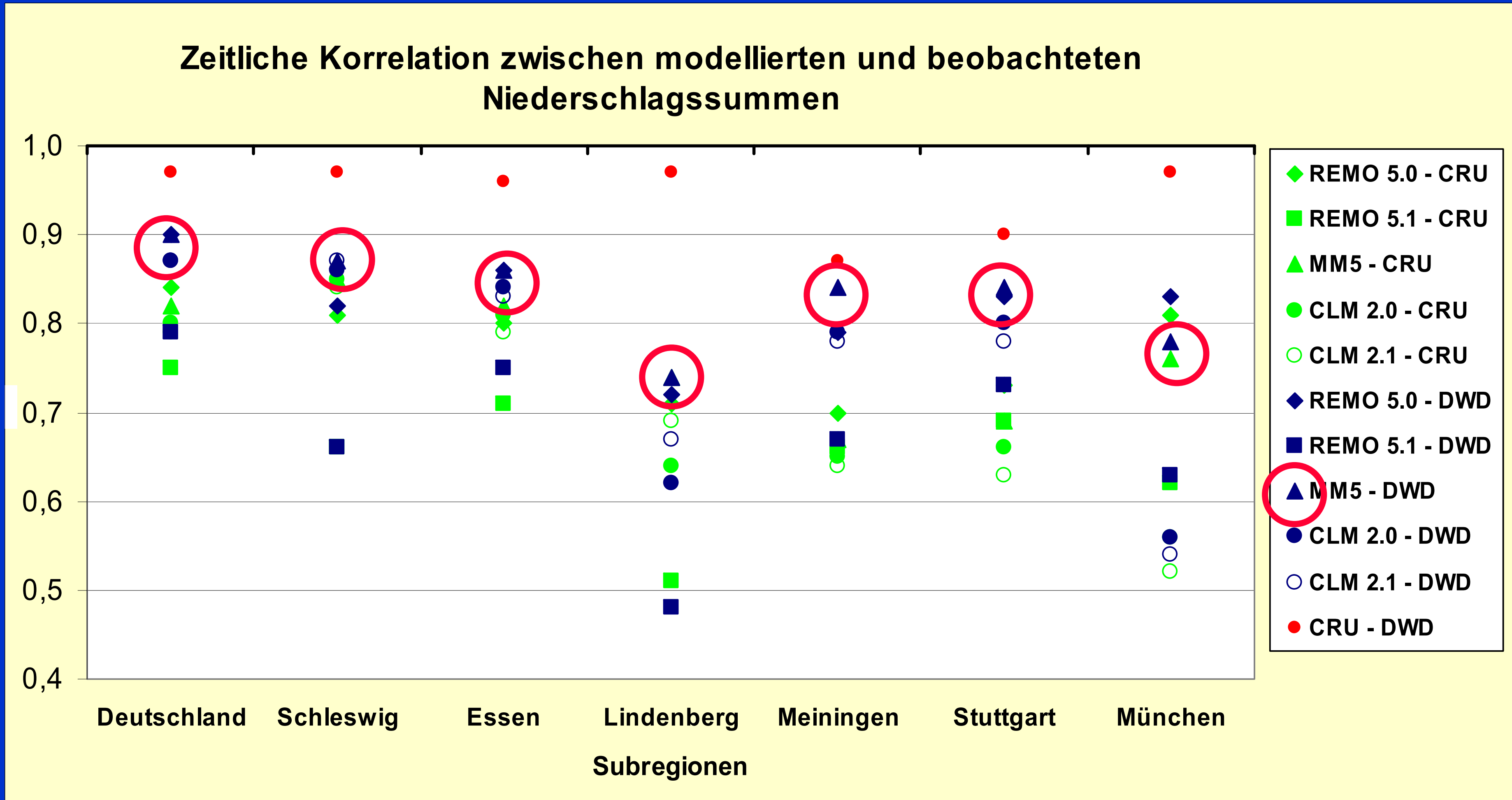
Accounting for soil-vegetation-atmosphere feedback effects

Model Intercomparison Mean Annual Precipitation (1979-1993):

Difference model results & DWD station data



Model Intercomparison Mean Annual Precipitation (1979-1993):
Difference model results & DWD station data



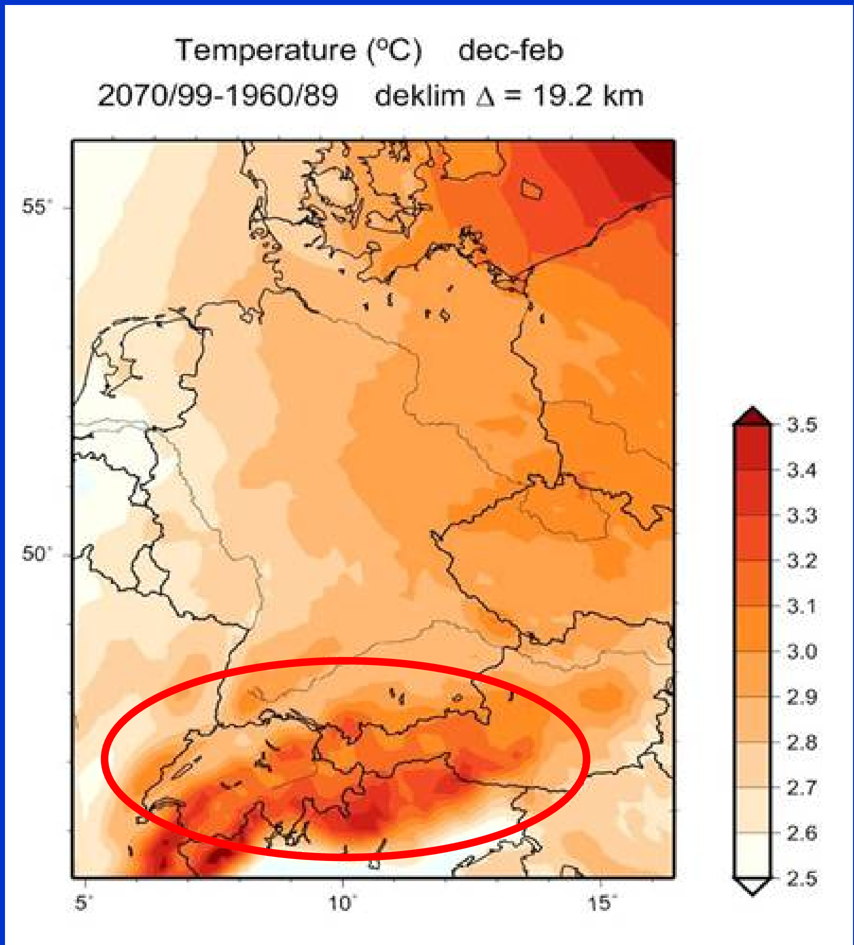
Performance of MM5 compared to other models

Example

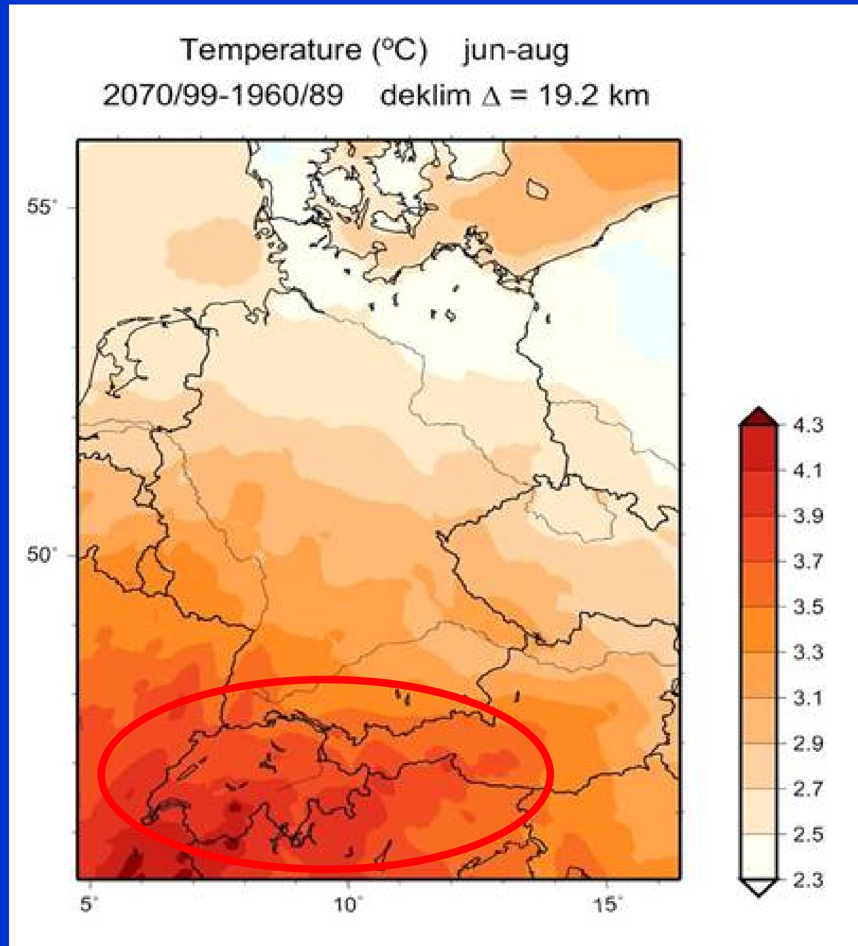
Regional Climate Change

Germany/Southern Germany & Alps

Regional Climate Change Germany

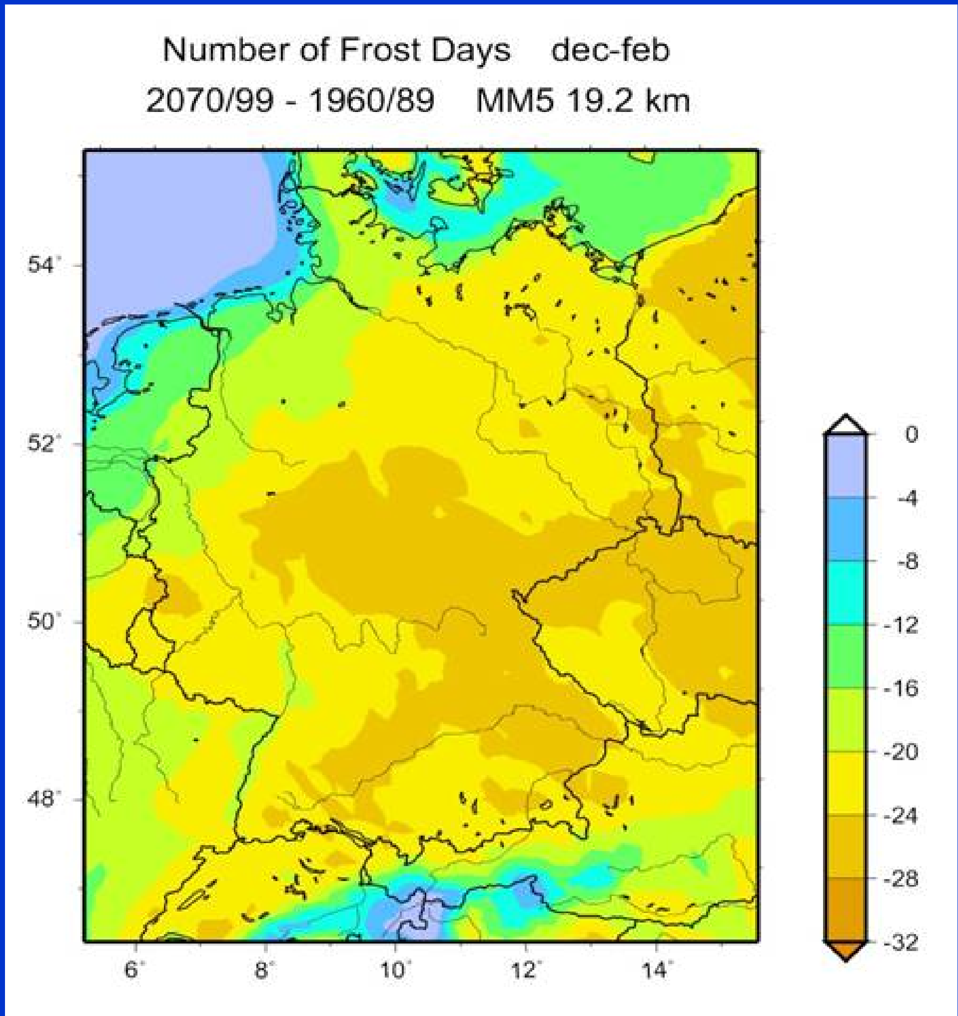


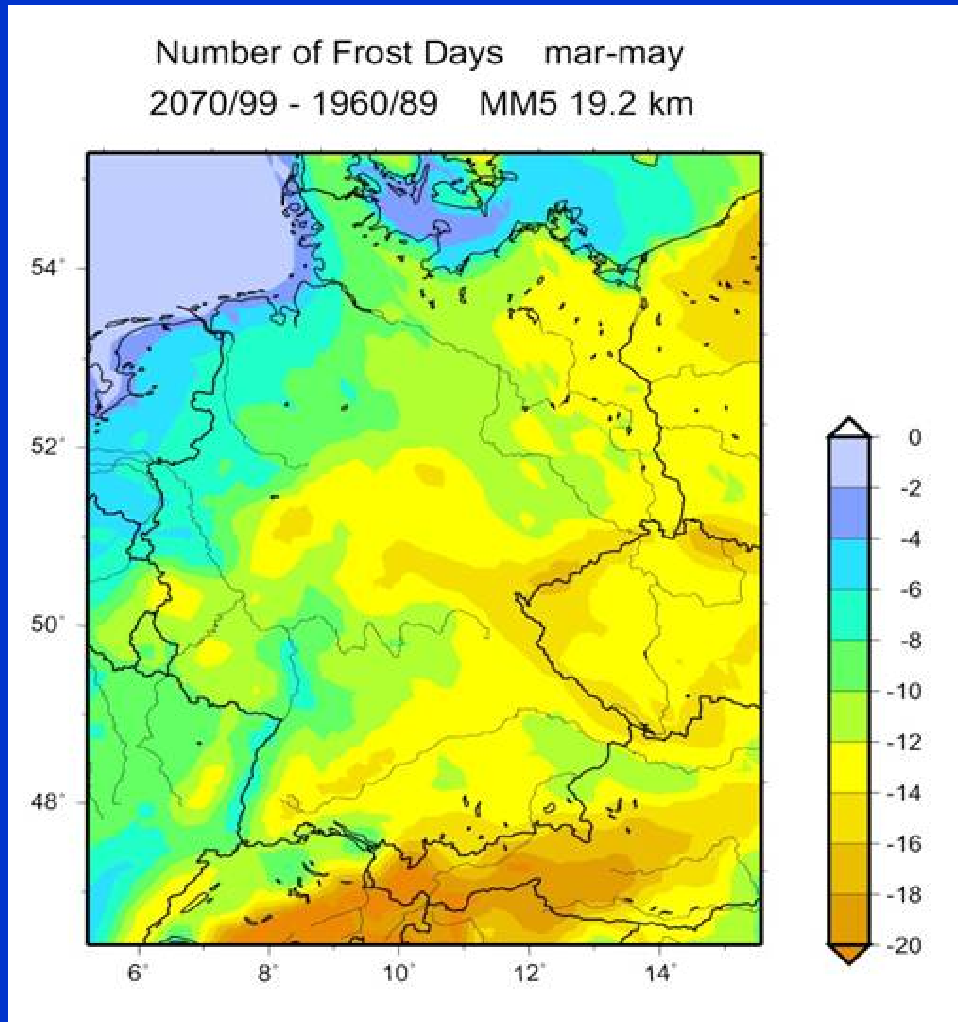
Winter



Sommer

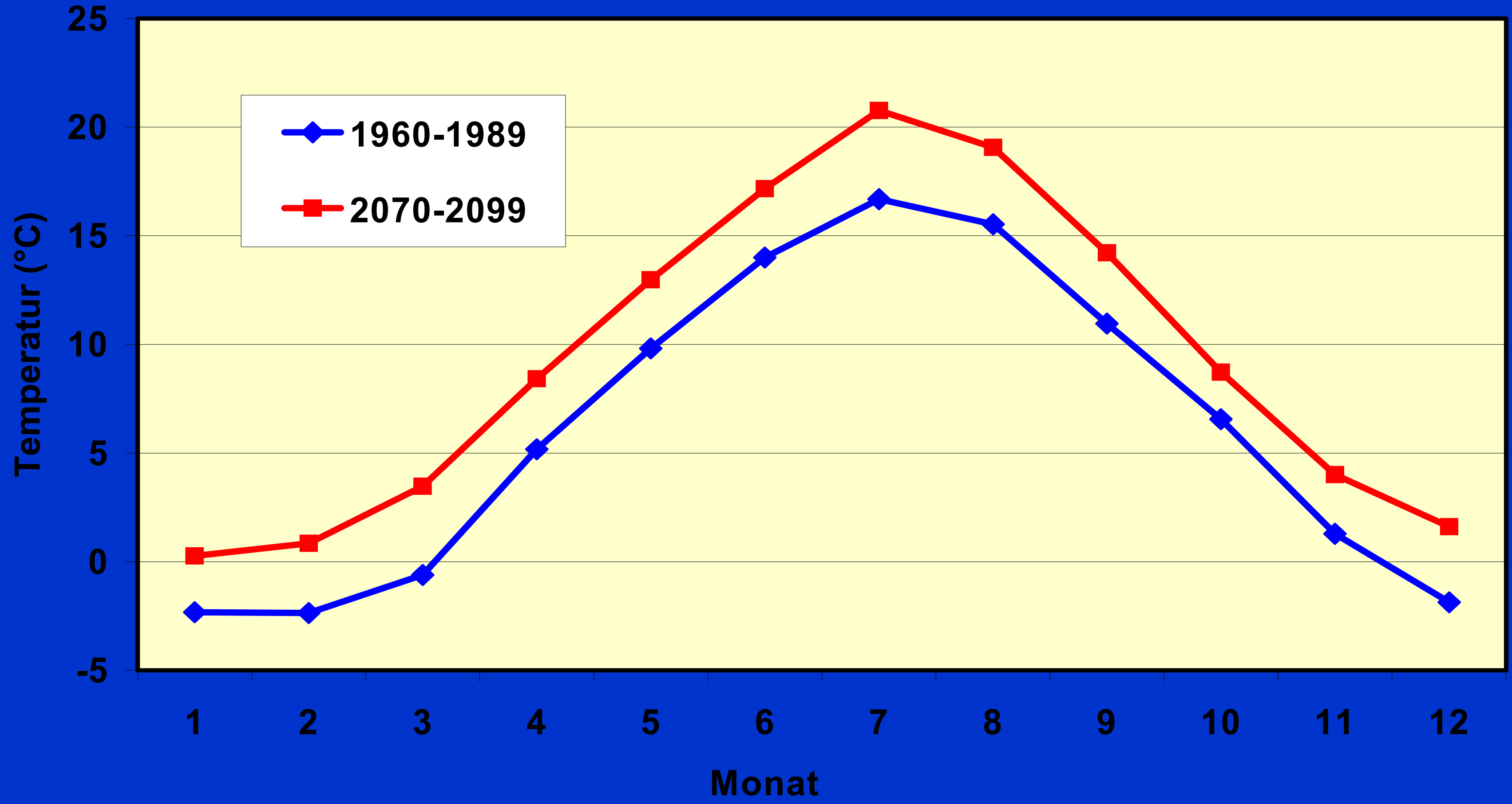
Alpine area: 3-4°C „hot spot“ in Europe


Number of Frost Days dec-feb
2070/99 - 1960/89 MM5 19.2 km
54°
52°
50°
48°
6°
8°
10°
12°
14°
0
-4
-8
-12
-16
-20
-24
-28
-32

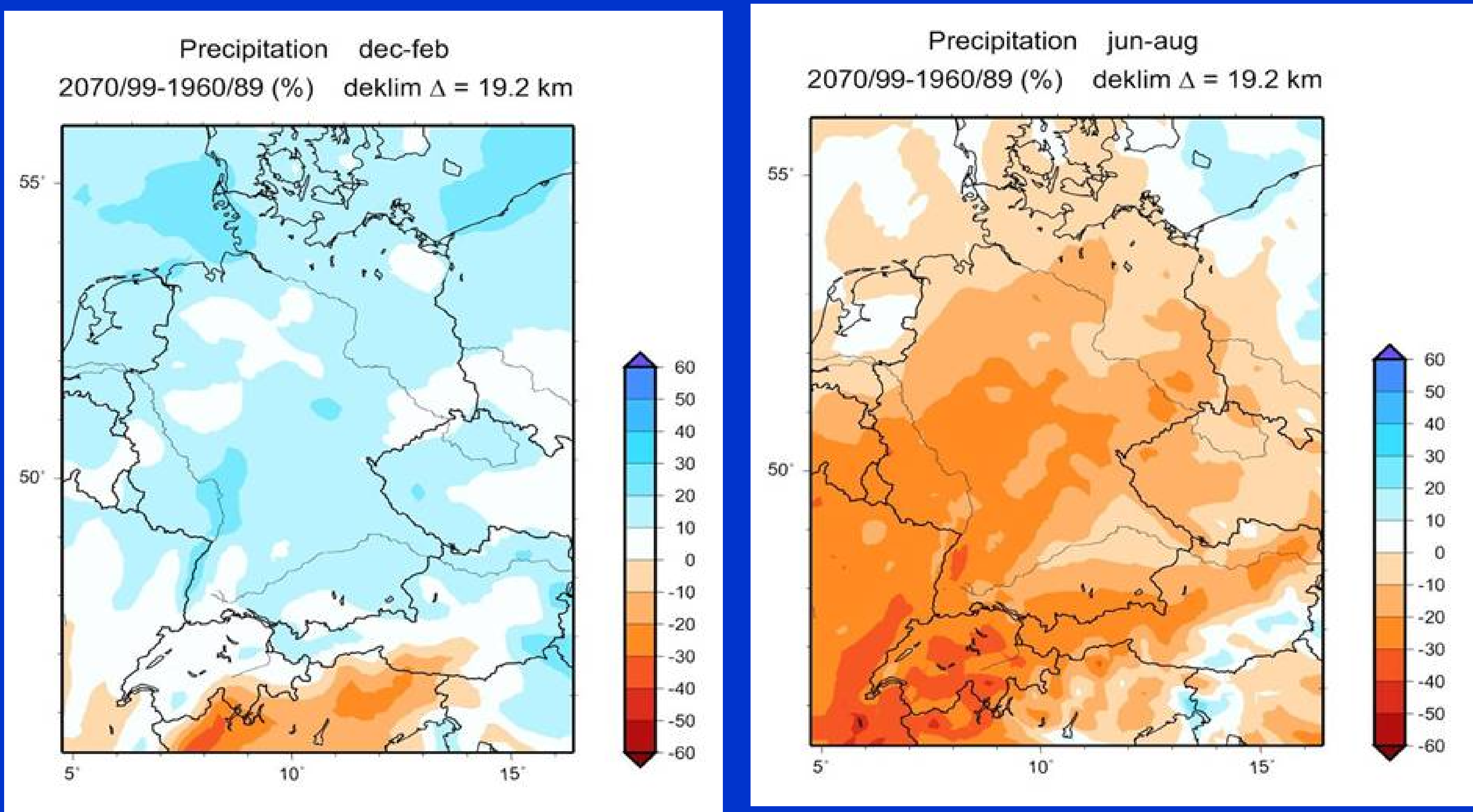

Number of Frost Days mar-may
2070/99 - 1960/89 MM5 19.2 km
54°
52°
50°
48°
6°
8°
10°
12°
14°
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20

Regional Climate Change Southern Germany

Temperature Change [°C] , 2070-99 vs. 1960-89, Δ=19km



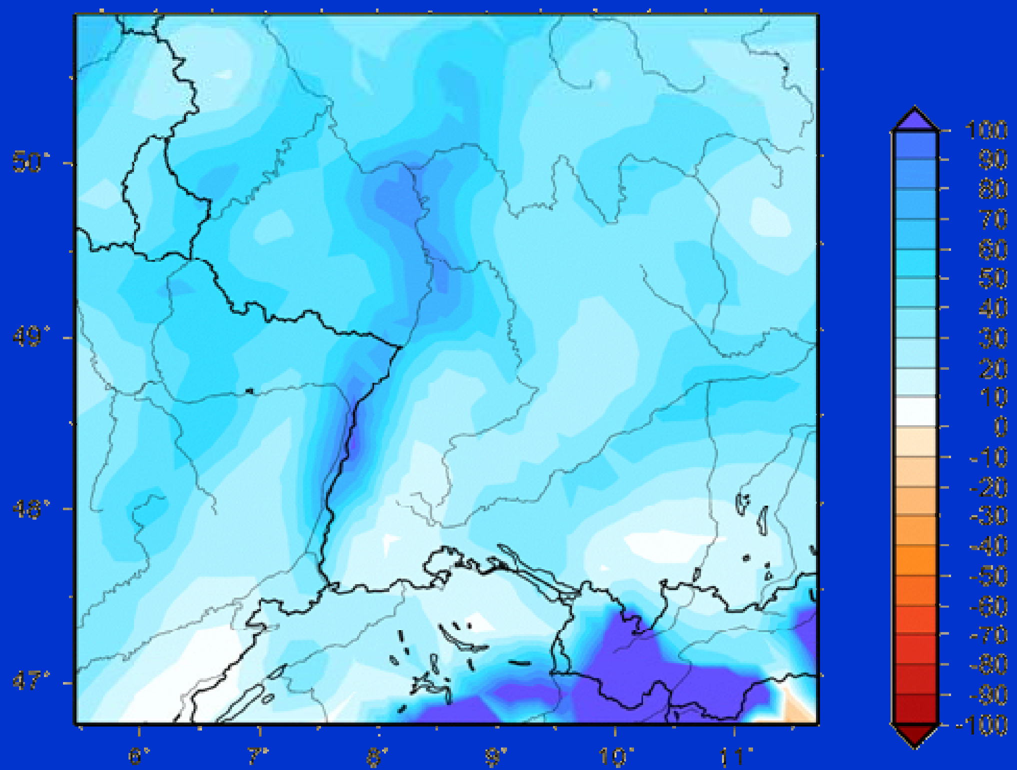
Regional Climate Change Germany



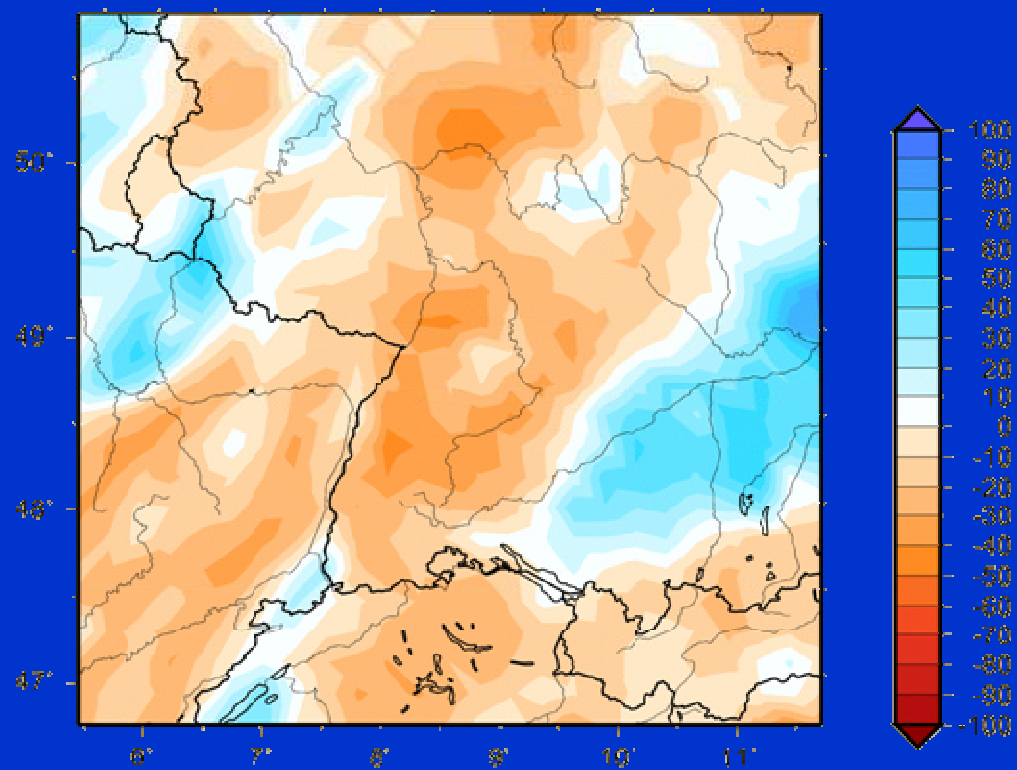
Up to 30% more precipitation in winter (Europe ≈ +11%)
Up to 40% less precipitation in summer (Europe ≈ -1%)

Regional Climate Change South West Germany

Surface Runoff Change [%], 2070-99 vs. 1960-89, Δ=19km



Winter DJF



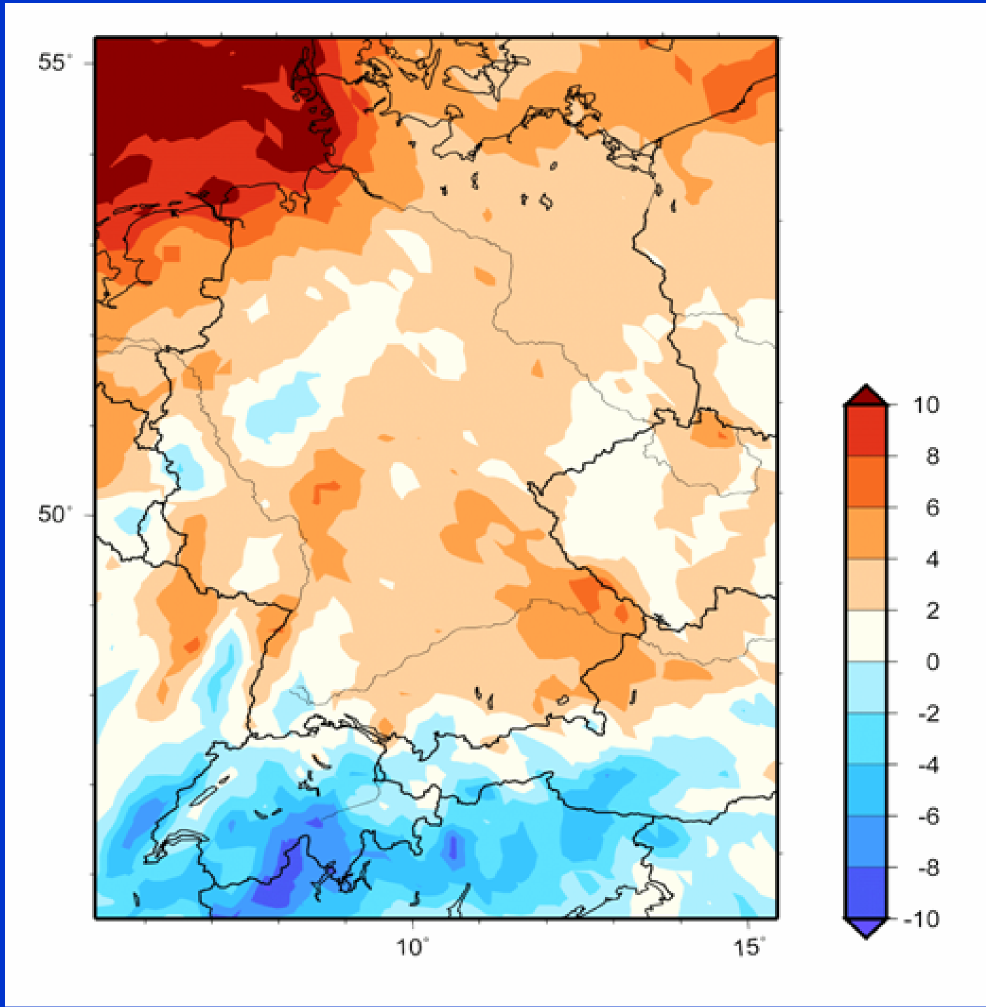
Summer JJA

Up to 80% more surface runoff in winter

Up to 50% less surface runoff in summer

Regional Climate Change Germany

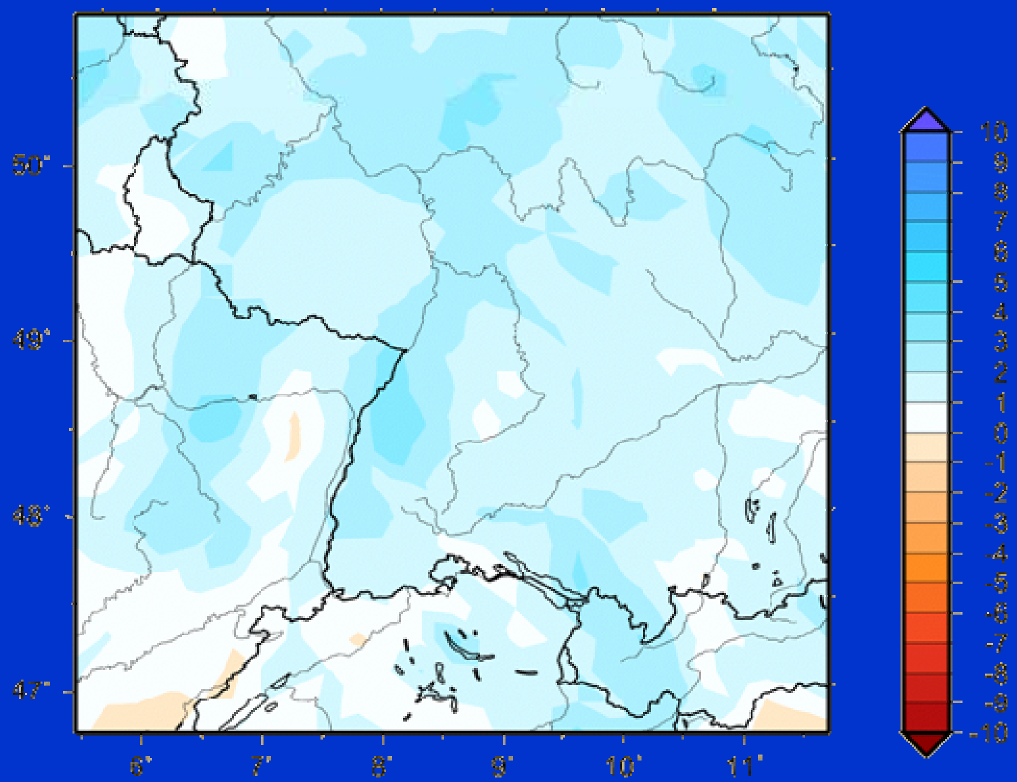
Change in frequency of heavy precipitation (2070-99 vs. 1960-89)



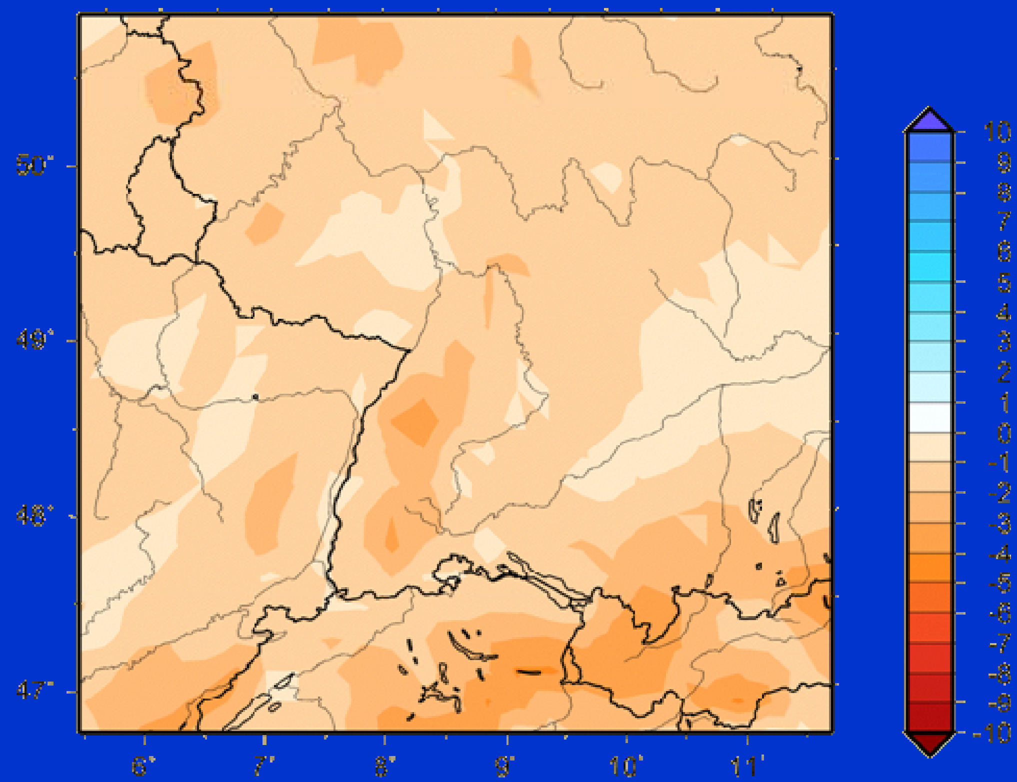
Change in number of days/year P > 10 mm

Regional Climate Change South West Germany

Change in frequency of heavy precipitation P > 10mm



Winter DJF



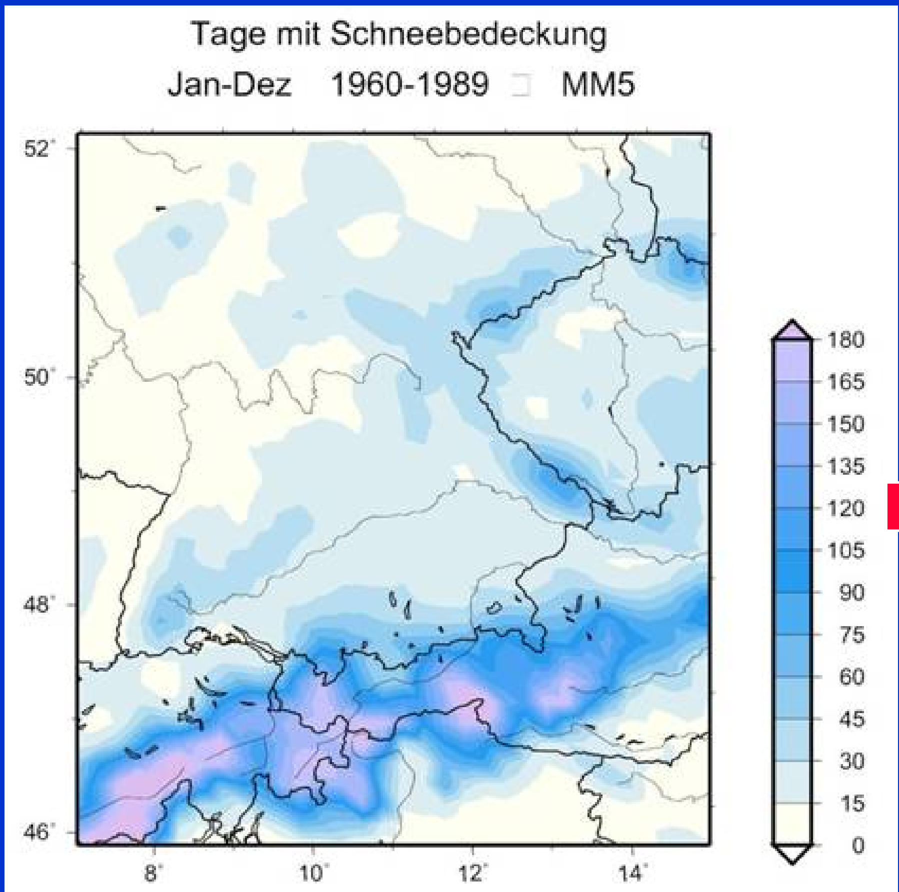
Summer JJA

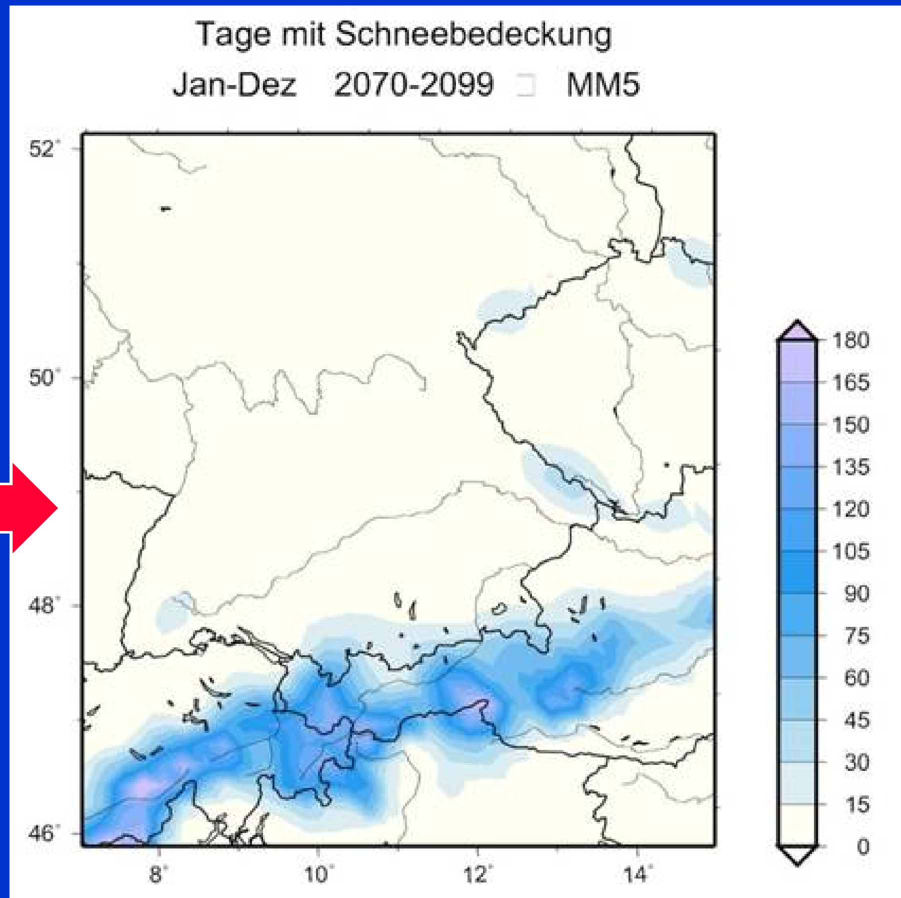
Increase of days with heavy precipitation in winter

Decrease of days with heavy precipitation in summer

Regional Climate Change

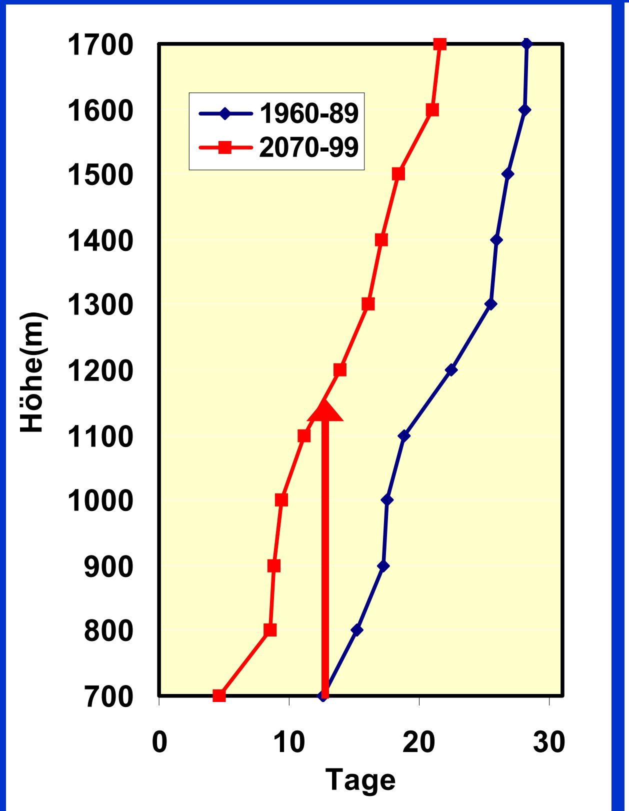
Days with Snow Cover



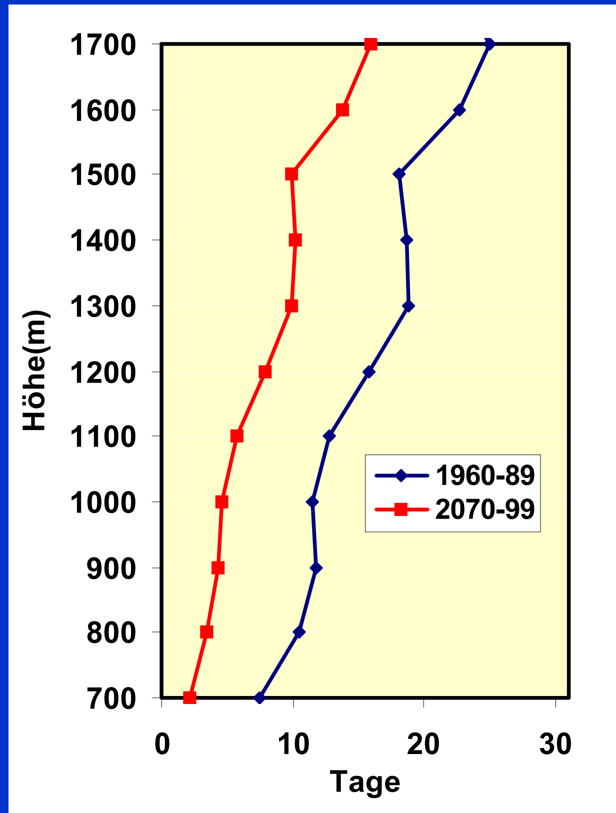


Decrease of number of days with snow cover

Regional Climate Change: Northern Alpine Area



January



March

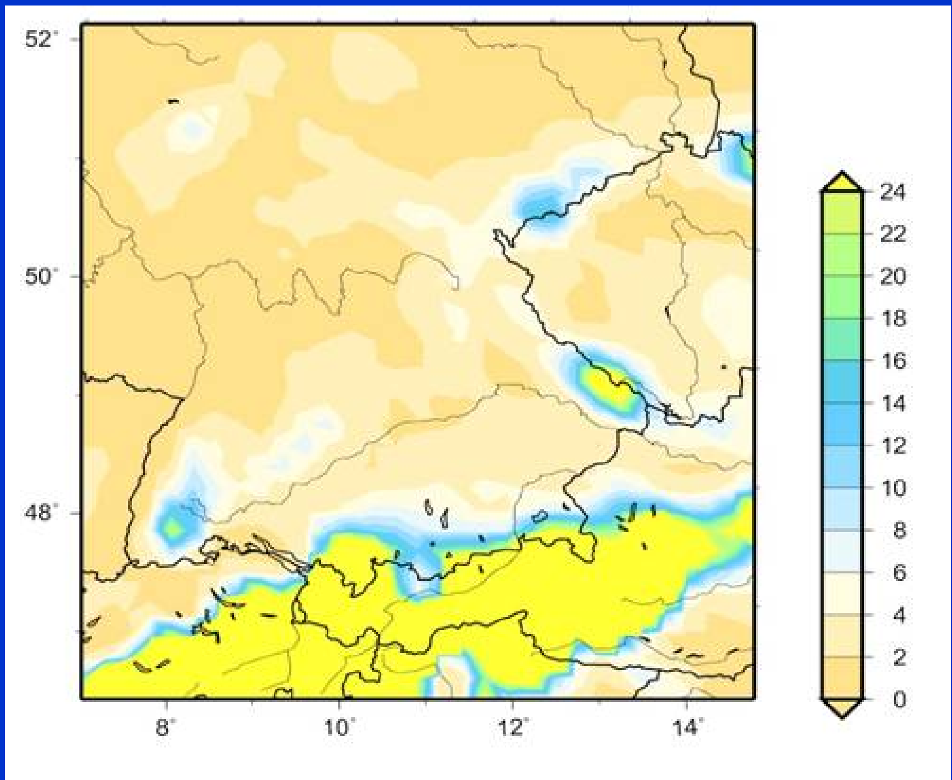
Days with
Snow cover

Changes of snow cover with height: ≈ 500m

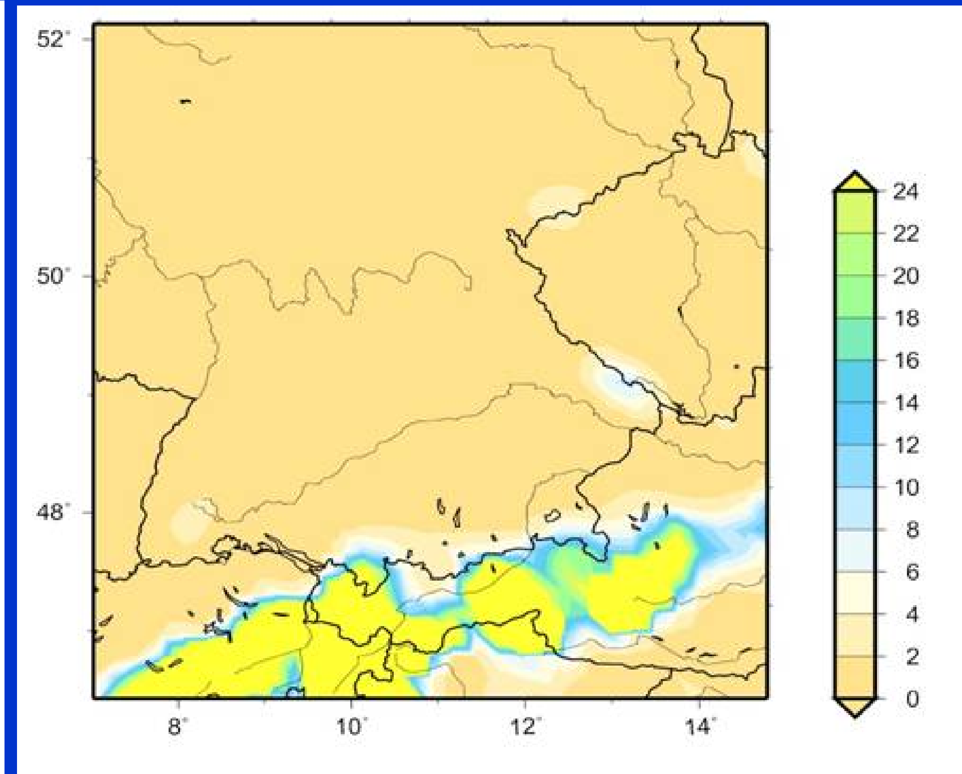
⇒ Runoff amplification

Snow mass in [mm] water equivalent Dec-Feb

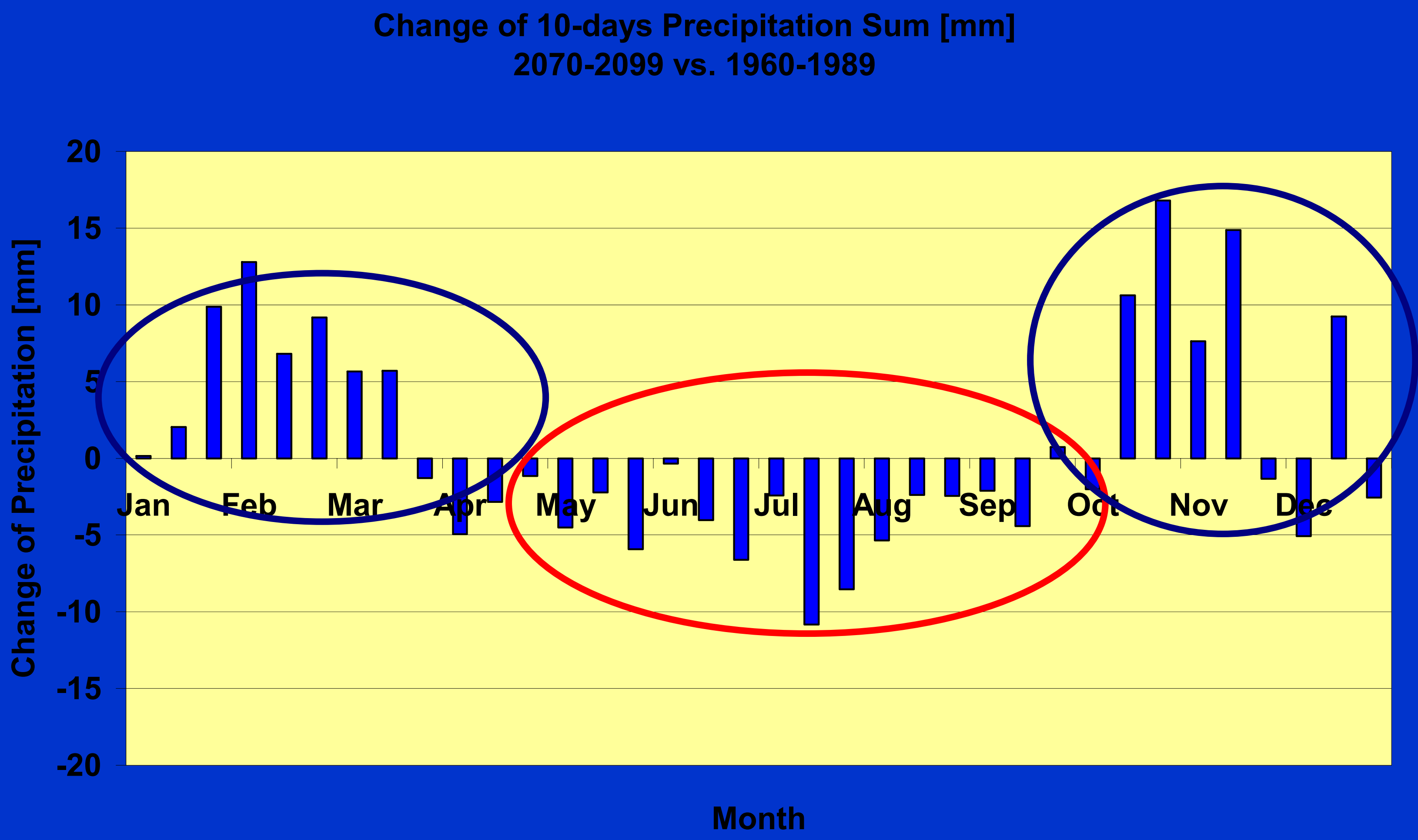
1960-89



2070-99

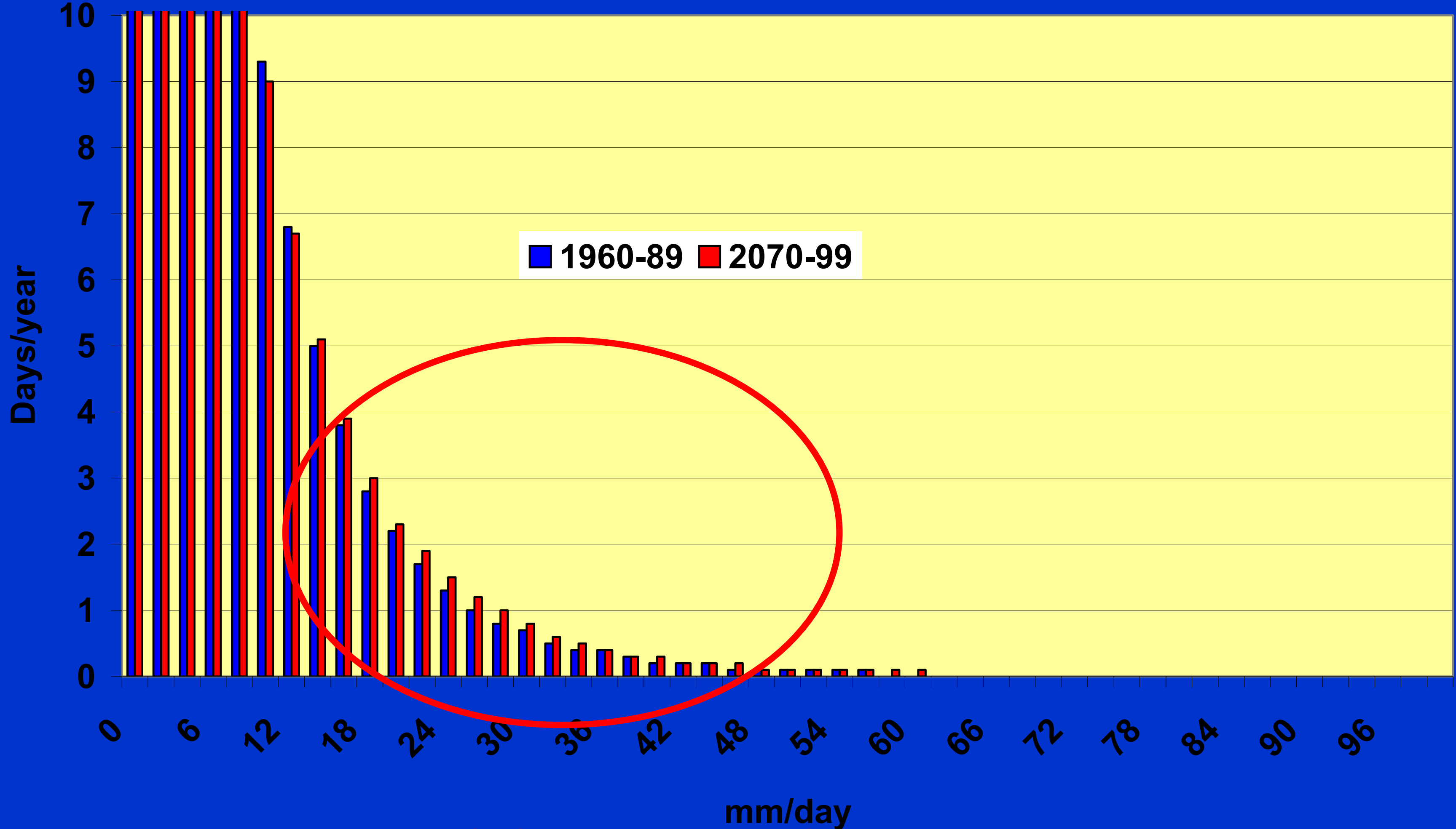


Regional Climate Change South West Germany



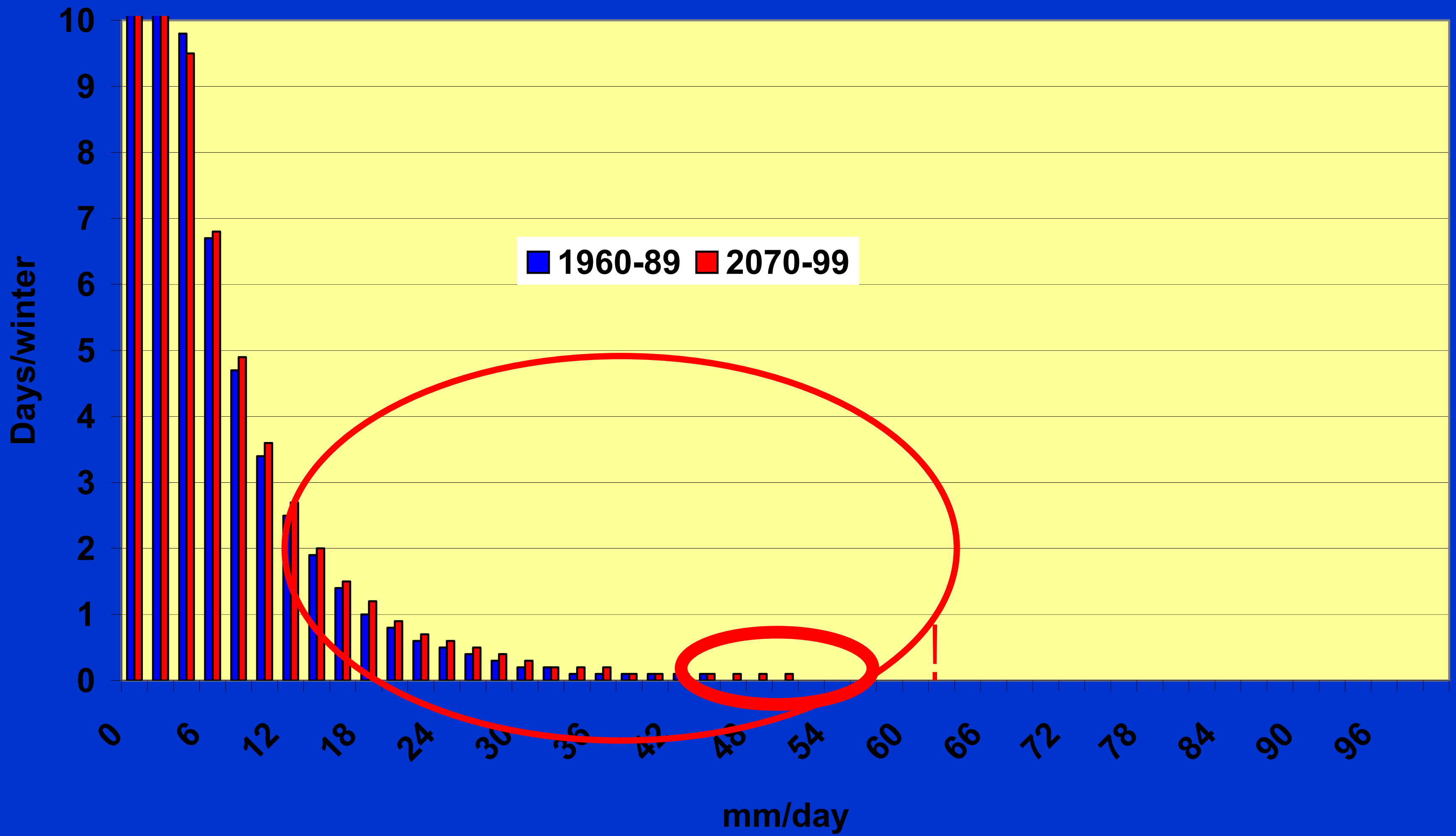
Increased winter-, decreased summer precipitation

Regional Climate Change South West Germany



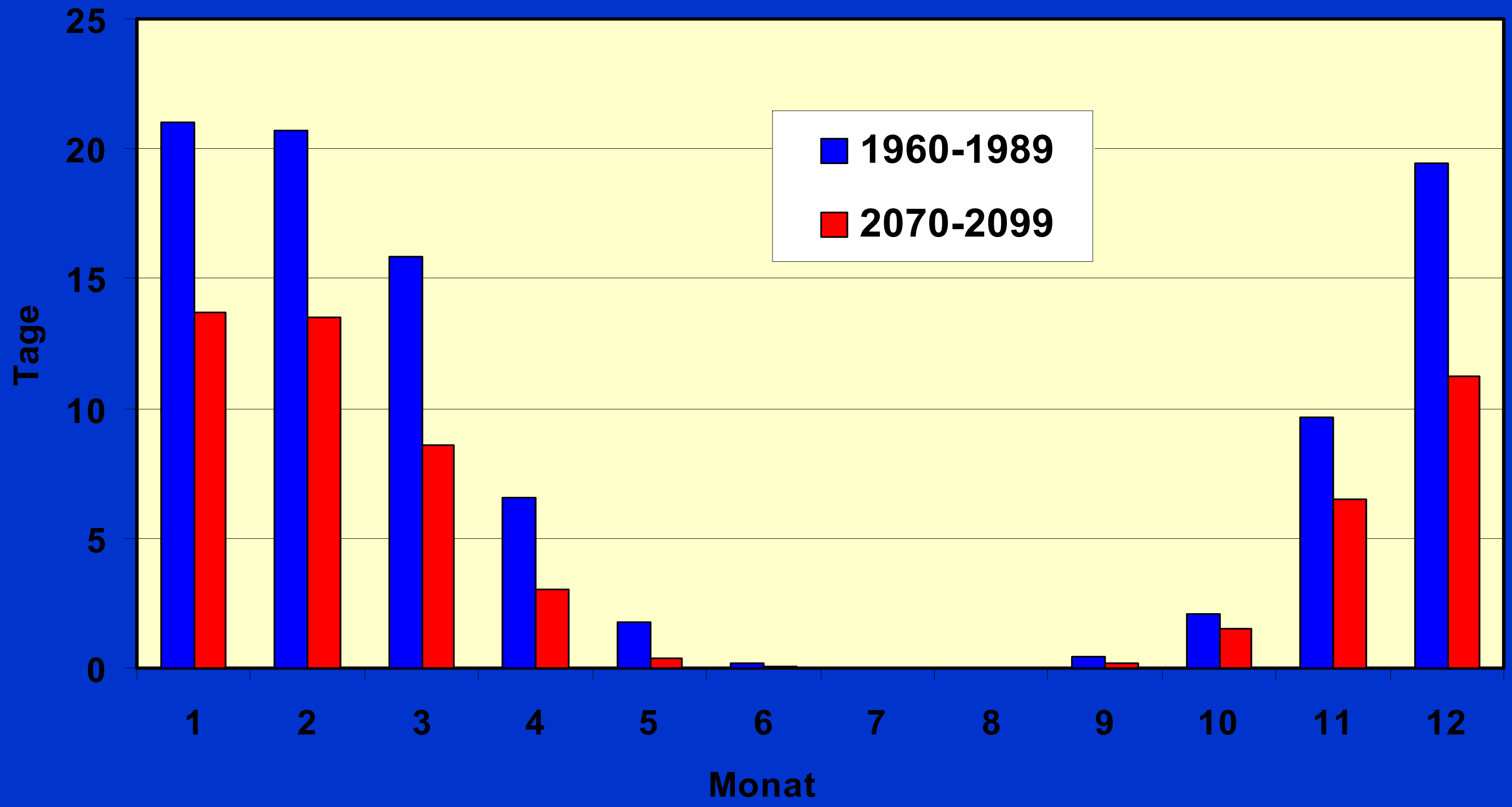
Increase of frequency of heavy precipitation

Regional Climate Change South West Germany



Winter (DJF): Increase of frequency of heavy precipitation

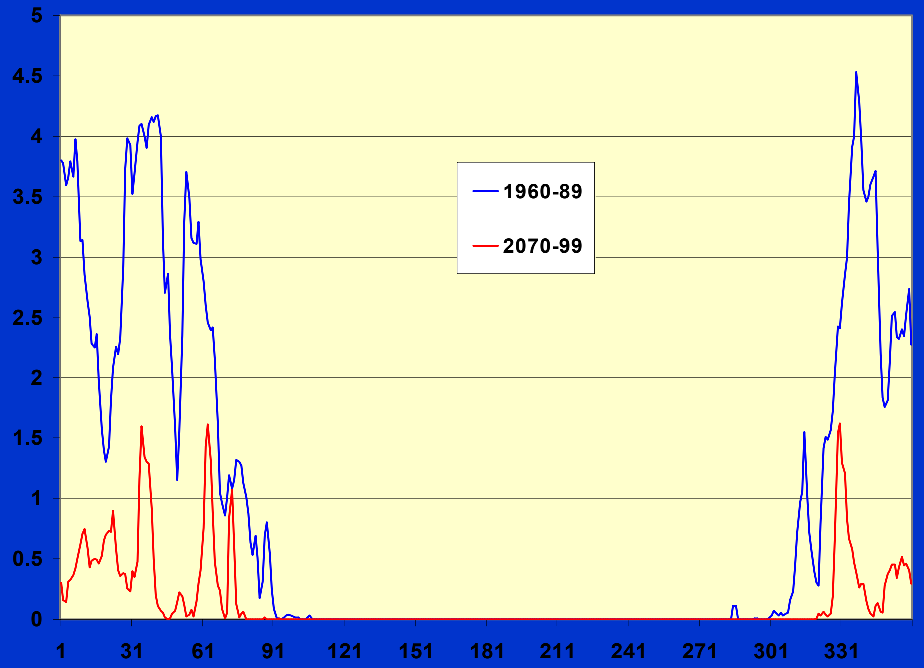
Days with Snowcover in Southern Bavaria and Northern Edge of EastAlps



Annual Course of Snow Masses ([mm] water equivalent)

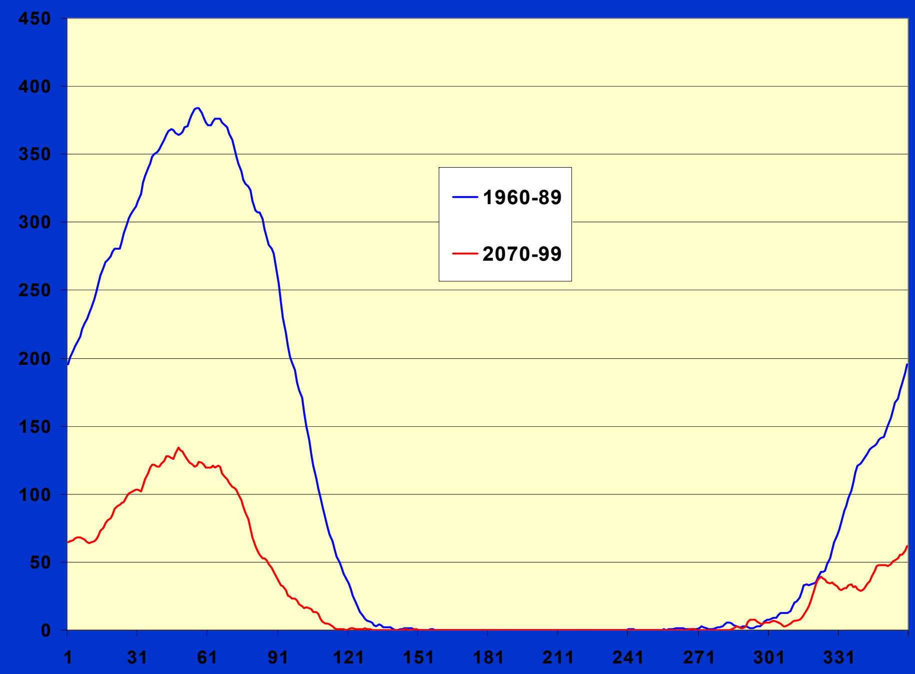
Prealpine area

350 – 600 m (480 m)



Northern edge of Alps

1300 – 1950 m (1700 m)



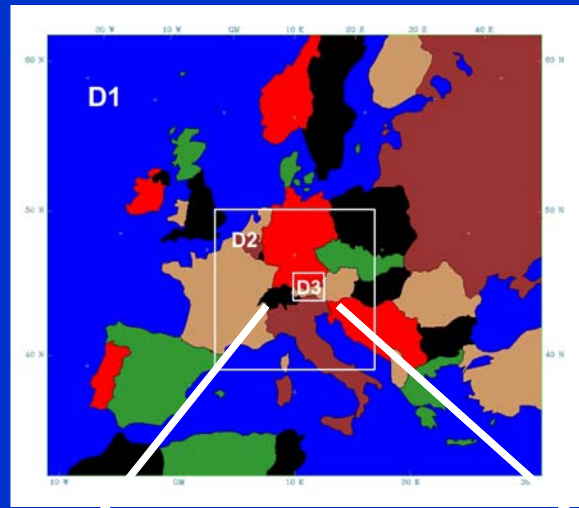
Coupled Regional Climate/Hydrology Simulations

1-Way Coupled Simulations

- Temperature
- Precipitation
- Wind
- Relative Humidity
- Global Radiation

MCCM
3-dim
Atmospheric model

Δt=12s

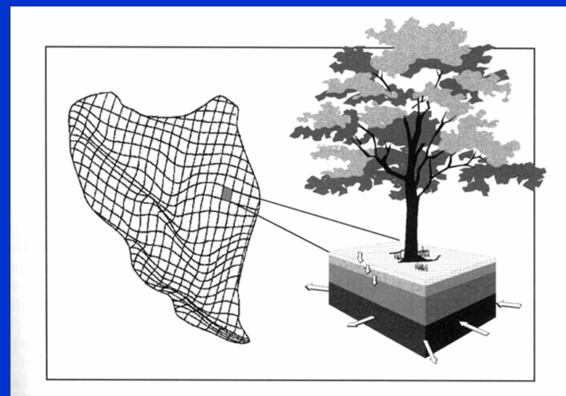


2.8x2.8° → 4x4 km² Resolution

WaSiM
Distributed Hydrological
Modell

Δt=8h

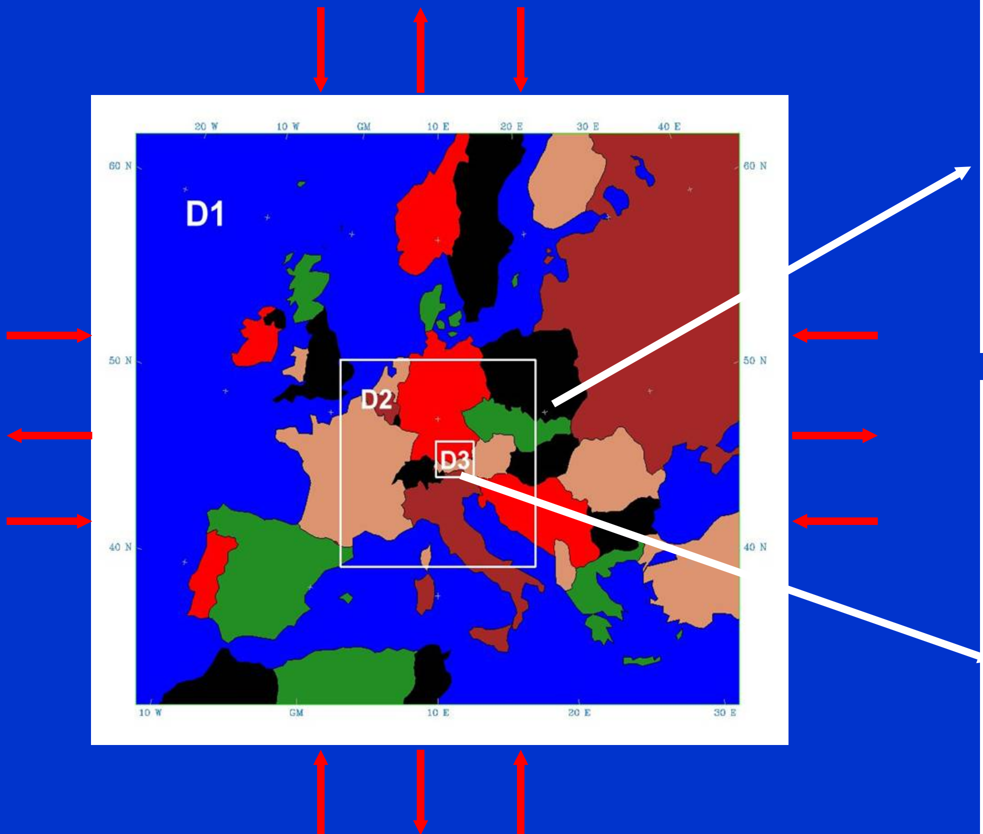
- Orography
- Land Use
- Soil Properties
- Aquifer Properties
- Flownet Structure

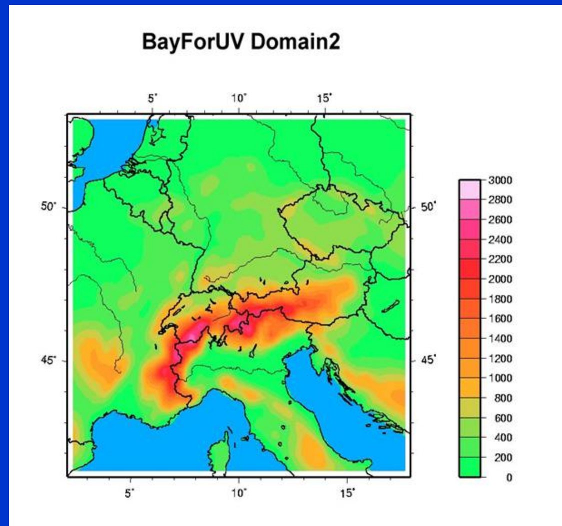


100x100 m² Resolution

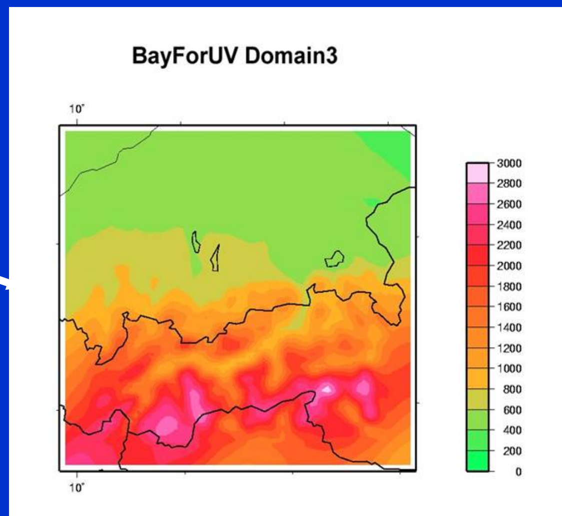
Evapotranspiration **Infiltration** **Surface Runoff** **Groundwater Flow**

Explicit dynamical Downscaling of ECHAM4 fields





Resolution
20x20km^2



Resolution
4x4km^2

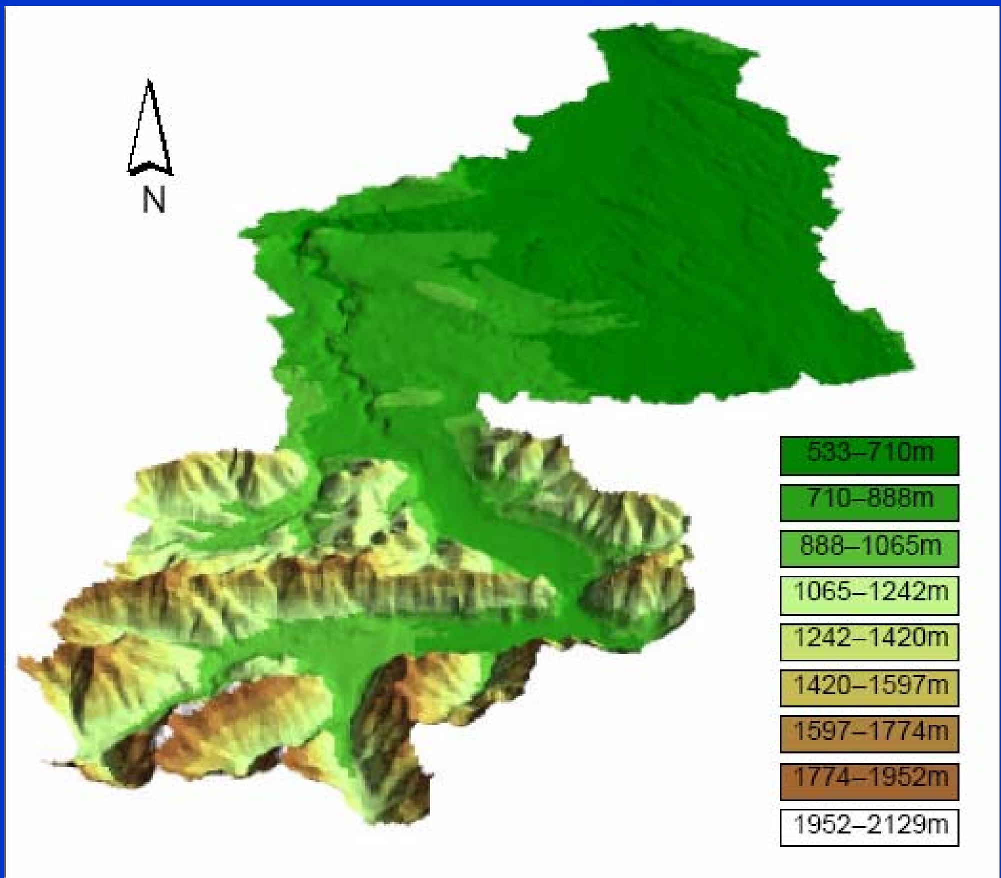
High resolution required for reproduction of orographically induced local phenomena

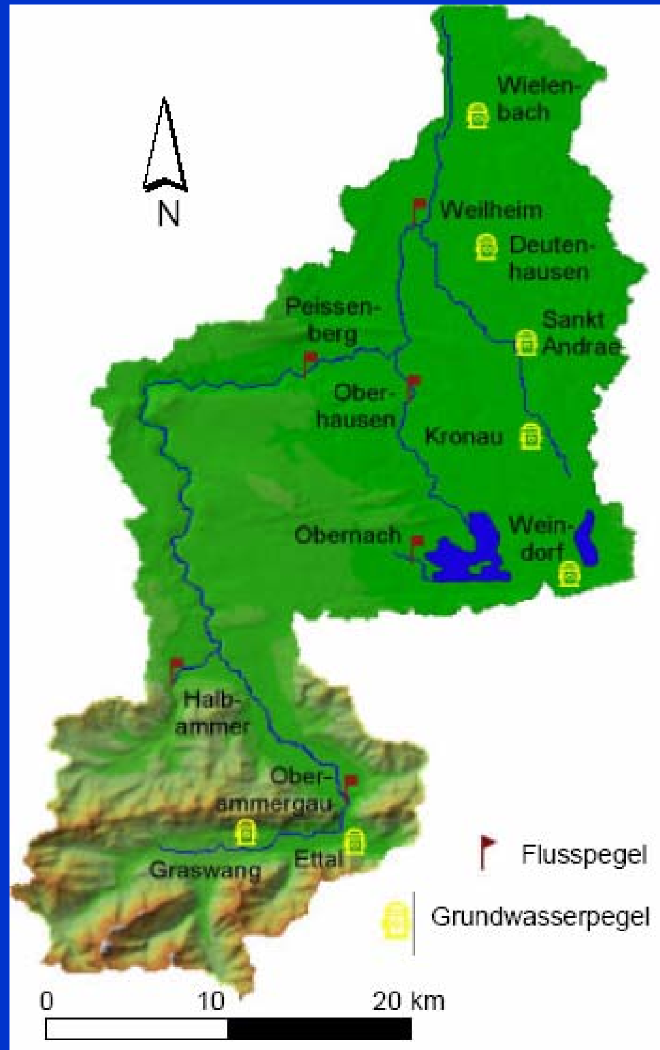
Case Study: The Catchment of the River Ammer

- Location: Southern Bavaria / Germany
- Area: 710 km^2
- Alpine/Prealpine environment
- Complex orography

- Elevation: 530-2190m above sea level
- Mean precipitation: 1400 mm/a (67% in summer)
- Days with snow cover: 127/a
- Temperature gradient: ≈ 0.6 °C/100m

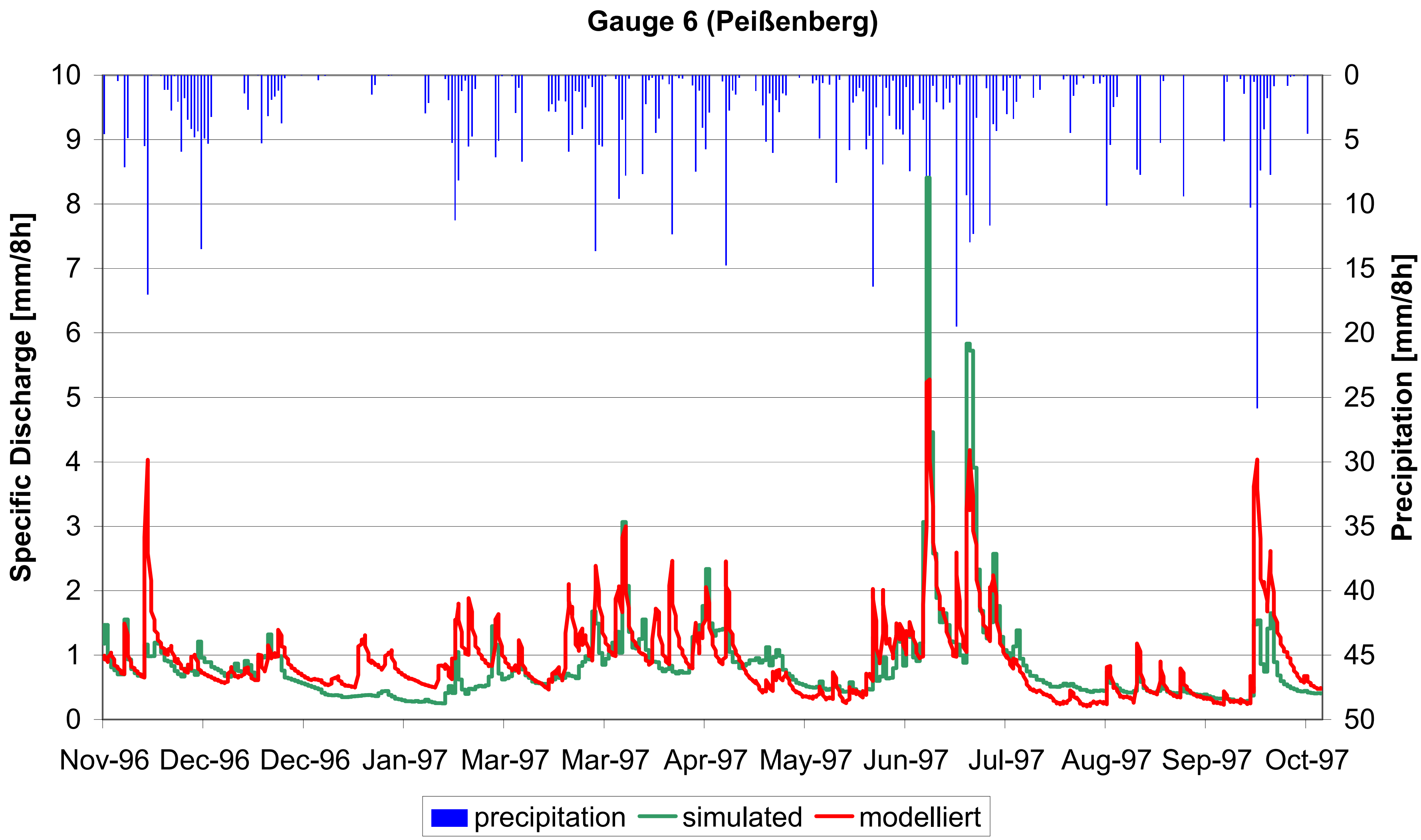
The Catchment of the River Ammer





The Distributed Hydrological Model WaSiM (Schulla & Jasper 2000)

- Physically based algorithms for most process descriptions
- Infiltration (Green & Ampt, 1911)
- Flow trough unsaturated zone (Richards, 1931)
- Suction head & hydraulic conductivity according to (van Genuchten, 1976)
- Evapotranspiration: soil and vegetation specific (Monteith, 1975; Brutsaert, 1982)
- Snow accumulation & -melt (“day-degree”, Anderson, 1993)
- Translation & retention of infiltration excess to sub basin outlet (flow time zones)
- Discharge routing: cinematic wave
- 2-dim numerical groundwater model dynamically coupled to unsaturated zone

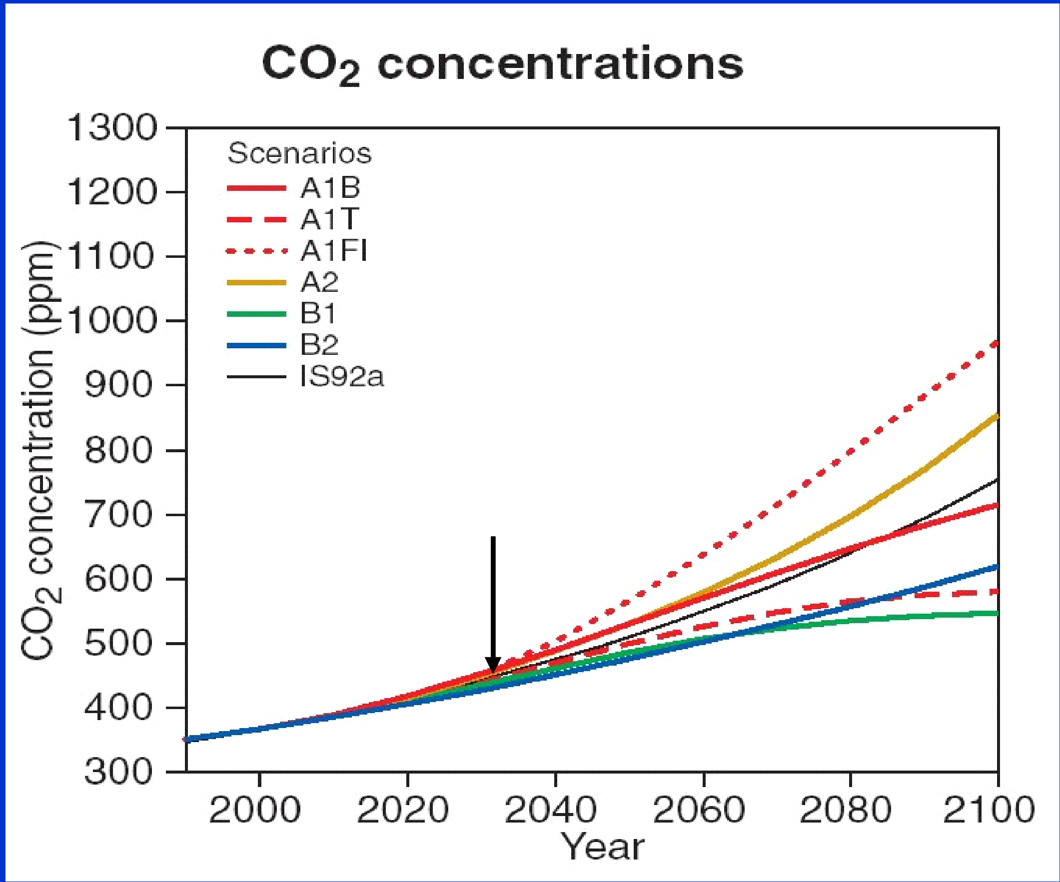

Gauge 6 (Peißenberg)
Specific Discharge [mm/8h]
Precipitation [mm/8h]
0
1
2
3
4
5
6
7
8
9
10
0
5
10
15
20
25
30
35
40
45
50
Nov-96
Dec-96
Dec-96
Jan-97
Mar-97
Mar-97
Apr-97
May-97
Jun-97
Jul-97
Aug-97
Sep-97
Oct-97
precipitation
simulated
modelliert

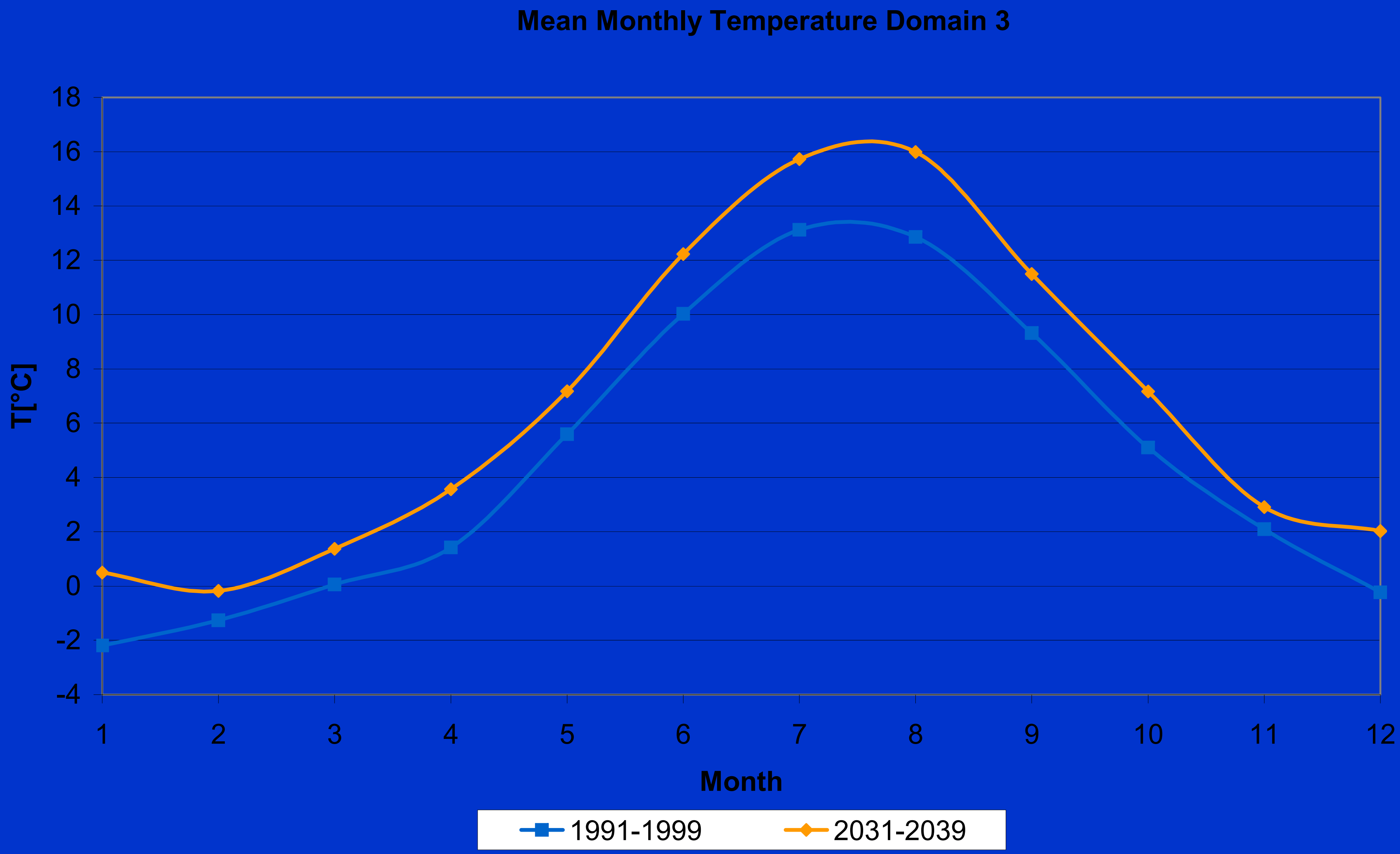
Climate Scenario IS92a

IPCC scenario IS92a
(*“business as usual“*)

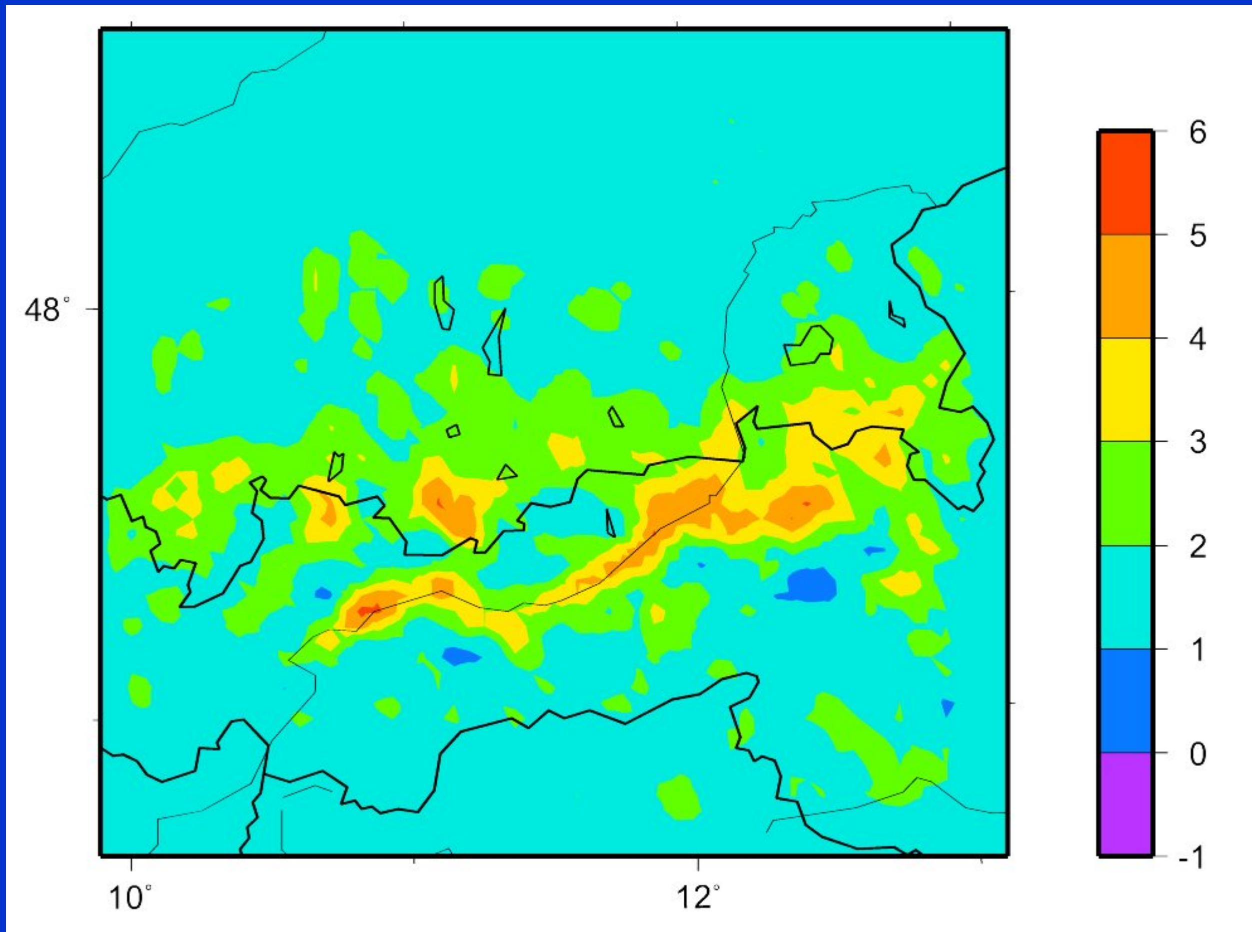
Increase of CO2: 28%

1990: 350 ppm
2030: 450 ppm

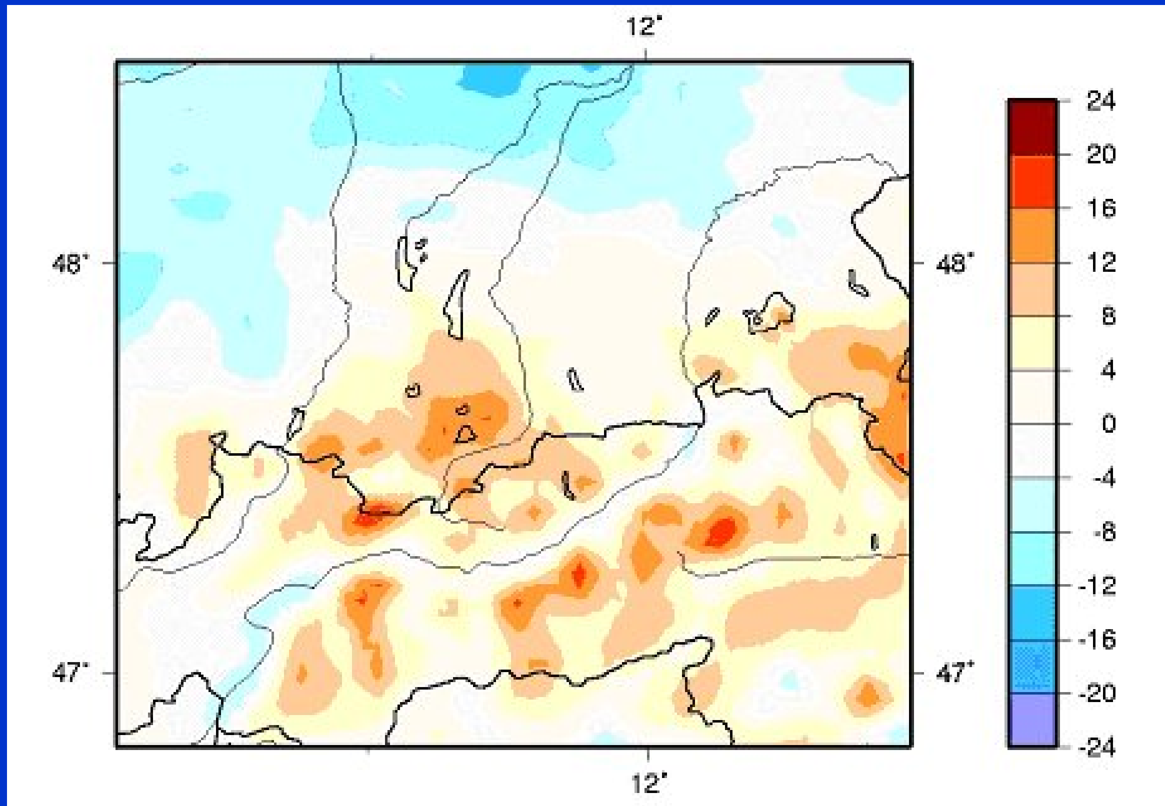



Mean Monthly Temperature Domain 3
18
16
14
12
10
8
6
4
2
0
-2
-4
T[°C]
1
2
3
4
5
6
7
8
9
10
11
12
Month
1991-1999
2031-2039

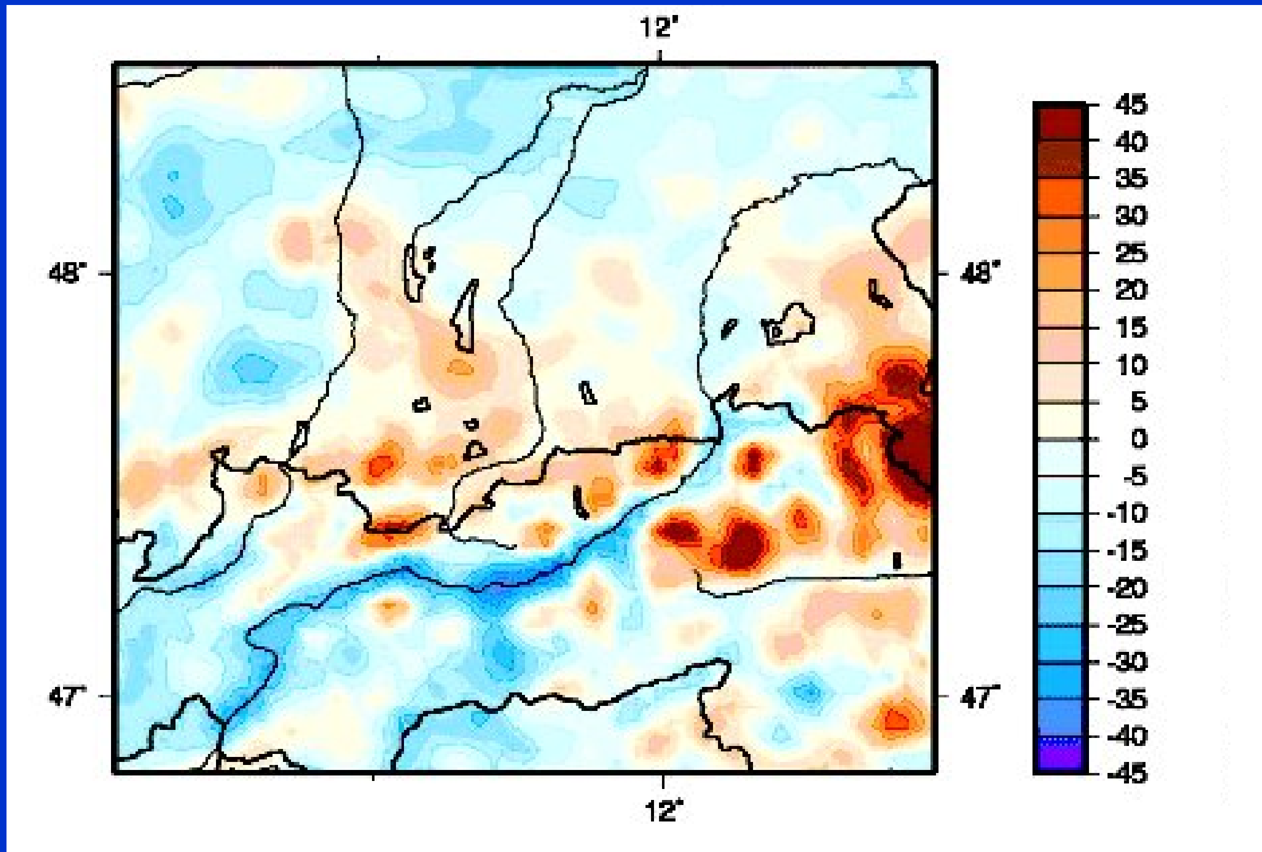
Change in mean annual temperature [°C] 2031/2039-1991/1999



Change in total annual precipitation [%] (2031/2039-1991/1999)



Change in winter (DJF) precipitation [%]
Change in summer (JJA) precipitation [%]



But: weak production of summer precipitation ⇒ bias correction applied (Kunstmann et al., 2004)

Validation and Assessment Strategy

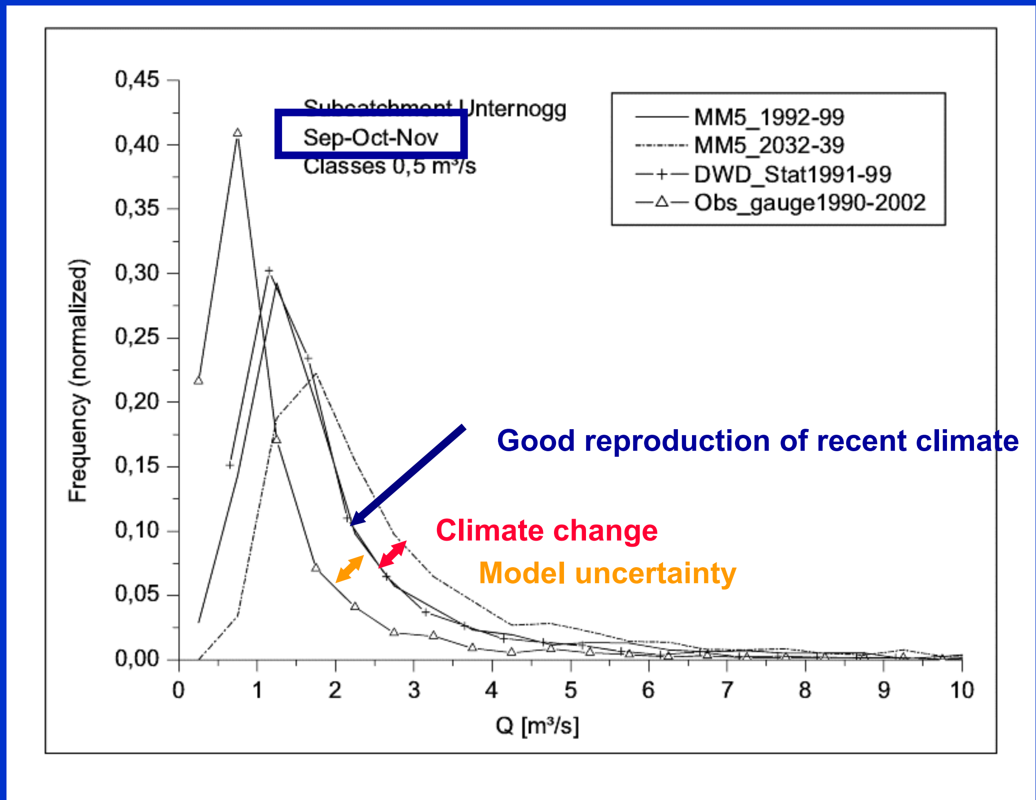
1) *ECHAM4-MCCM* driven hydrological simulation:
   IS92a scenario **1991-1999** using adjusted precipitation fields

2) *ECHAM4-MCCM* driven hydrological simulation:
   IS92a scenario **2031-2039** using adjusted precipitation fields

3) **Station interpolated** hydrological simulations
   using 15 meteorological stations DWD (**1990-1999**)

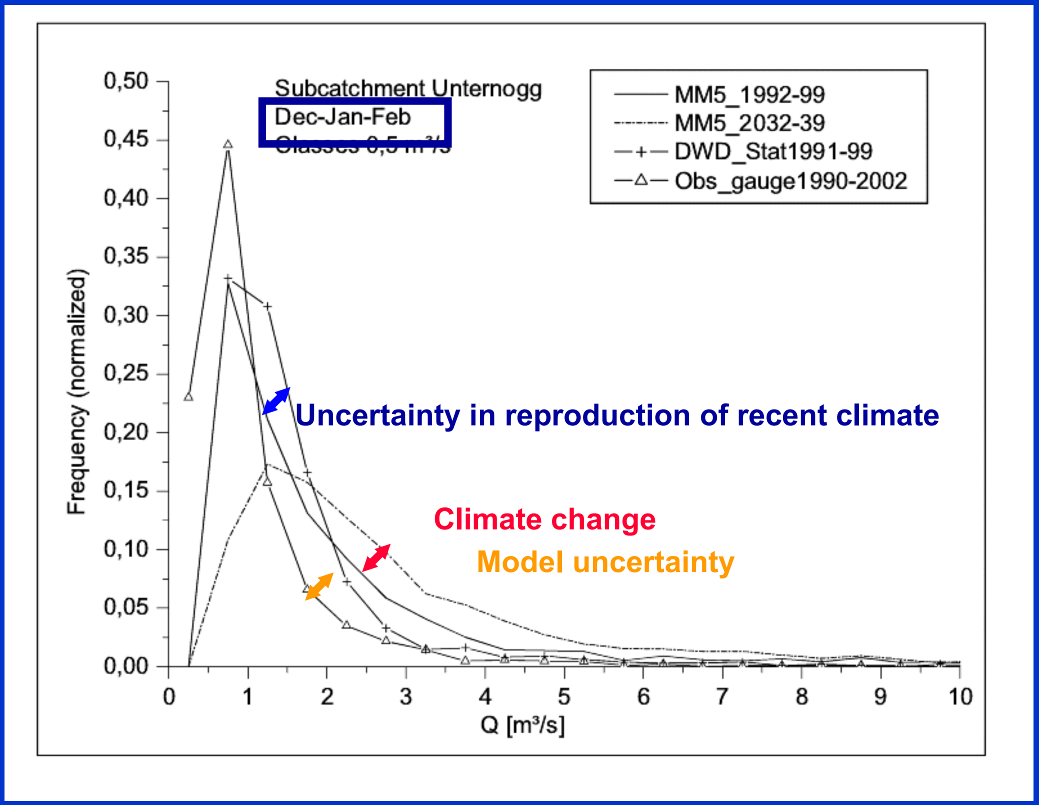
4) Comparison to **observed** runoff frequency distribution

Analysis of Runoff Frequency Distribution



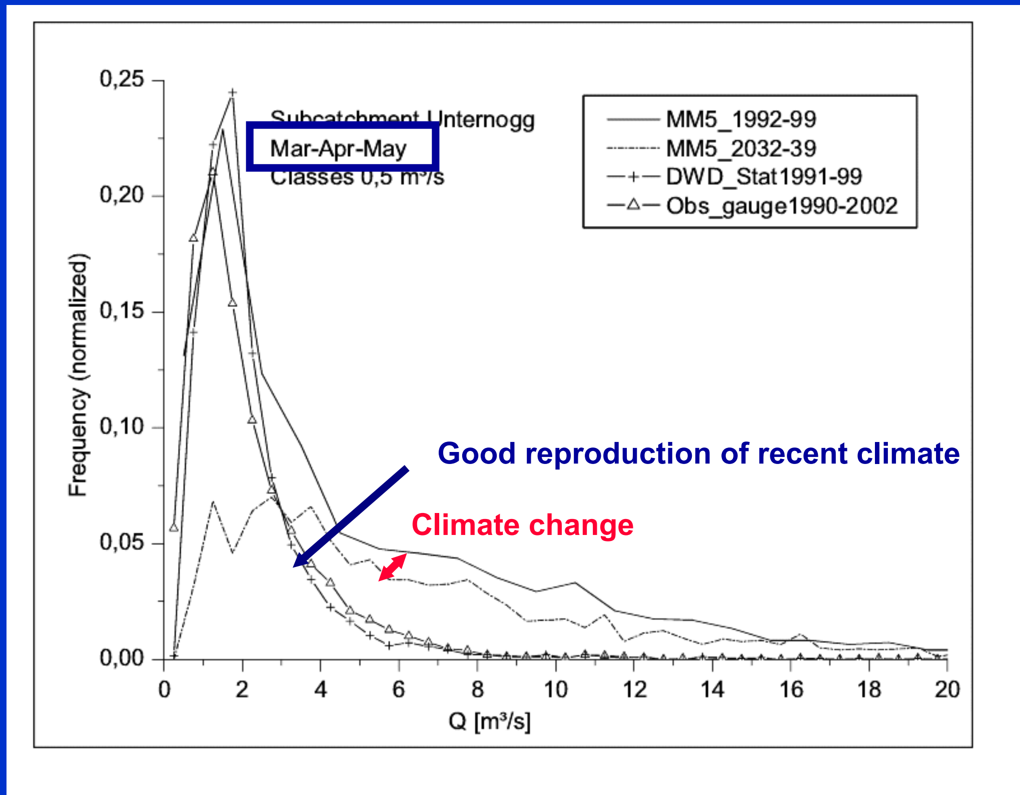
Gauge Unternogg

Analysis of Runoff Frequency Distribution



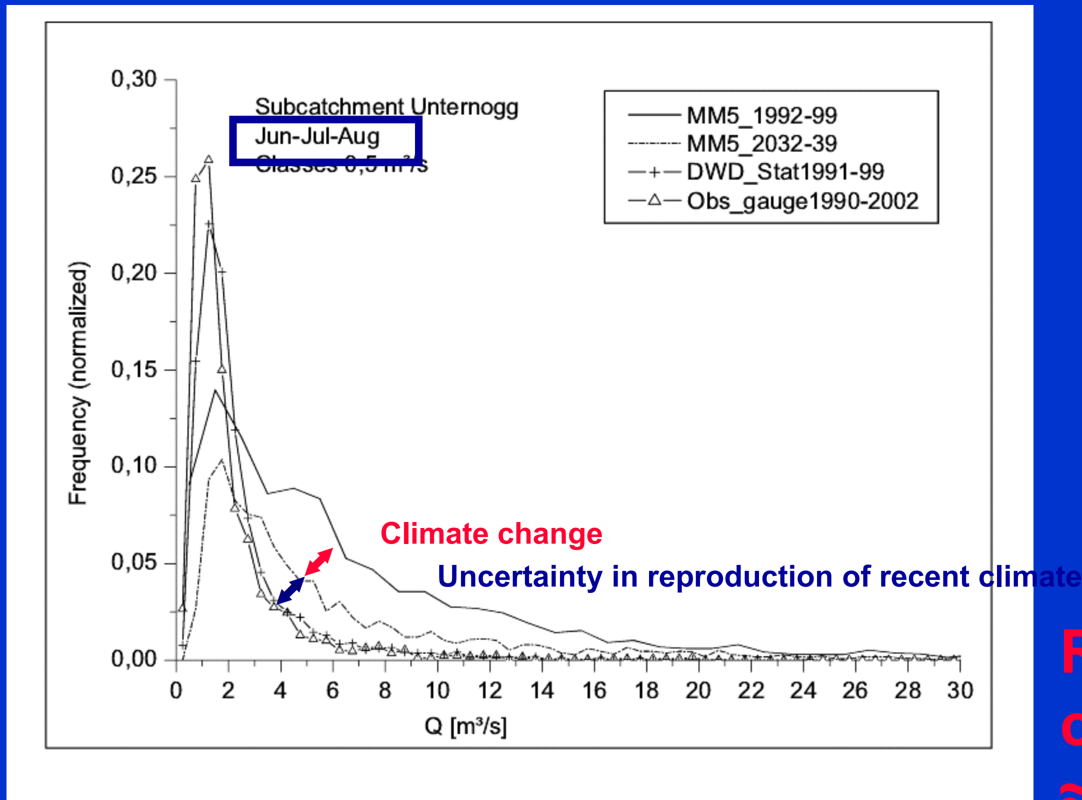
Gauge Unternogg

Analysis of Runoff Frequency Distribution



Gauge Unternogg

Analysis of Runoff Frequency Distribution



Gauge Unternogg

Range of climate change signal ≈ uncertainty range of hydrological modeling

Summary

- Mountain areas are climate sensitive regions:
  trends & changes larger than global averaged values

- Due to orography: small atmospheric circulation changes can induce large regional/local hydrometeorological changes

- Only regional climate change investigations can support decision makers and help desiging adaptation strategies and developing mitigation measures.

- Scientific challenge: separation of signal-to-noise ratio

Thank you for your attention